Effects on Arctic Grayling *(Thymallus arcticus)* of Short-Term Exposure to Yukon Placer Mining Sediments: Laboratory and Field Studies

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Yukon River Basin Study
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EFFECTS ON ARCTIC GRAYLING (*Thymallus arcticus*) OF SHORT-TERM EXPOSURE TO YUKON PLACER MINING SEDIMENTS: LABORATORY AND FIELD STUDIES

by

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PREFACE

These studies, with other preliminary work on food habits and the distribution of Arctic grayling, were carried out to provide some initial information on the effects of placer mining sediments on this species of fish. At the time the 1982 field work was planned, it was anticipated that a longer term programme of more comprehensive studies on the effects of sediment on various stages in the life cycle of grayling and their habitat would follow. While this work was directed primarily at sediment impacts on juvenile grayling, it was also recognized that a sound understanding of the ecology of the species is needed for management purposes.

Sensitive and well informed management of water resources, and the associated protection of fisheries values, will require much more research on the effects of sediment impacts on a wide variety of biological processes. Such research will require elucidation of the effects of, for example, the concentration of sediment, size, shape and hardness of particles, mixes of particle types and timing of discharge. Studies on many of these factors should be carried out on fish at various stages in their life cycle and in different seasons. In addition, studies on the effects of sediment and sediment characteristics on rheotactic behaviour, feeding behaviour, spawning behaviour, and the production of food organisms for fish, are required to support sound water use planning. Although it may be desirable to have information on this scale now for water resource decisions, it is not realistic to expect it after one year of research.

It is hoped that the work done in 1982, and considered in total, may be of value to the agencies that manage water resources for the public of Yukon. However, the authors would warn people not to use single components of the results to form guiding principles in water use decision making. For example, acute lethal bioassay tests, performed in otherwise protected conditions, do not in themselves indicate the effect of much lower concentrations of sediment on grayling in the wild which must find food, avoid predators, and maintain positions in a stream system over a prolonged period. Other species of fish have been shown to be able to tolerate exposure, in protected conditions, to short-term high concentrations of sediment. It has also been shown that the same species are affected adversely by much lower concentrations of sediment where physiological tests are considered or where reproduction and feeding are involved.

Parts of the work we carried out in 1982 indicate the nature of certain physiological responses of fish to suspended sediment. Other components investigated the distribution and food of grayling in a stream system receiving sediment from placer mining operations; the results of this work will be reported separately.

In this Preface the authors are not apologizing for the scale or quality of these initial studies. We are urging caution in interpretation and application of such first-stage research. In a broad sense we are stressing the need to understand cold-zone stream ecology, grayling biology, and the complex effects of various components of placer mining on them.

The Department of Fisheries and Oceans (Fisheries Research Branch and Field Services Branch) and the Yukon River Basin Study (a joint study by Canada, Yukon and British Columbia of the water and related resources of the Yukon basin) funded this project. Opinions expressed are those of the authors. The work was a co-operative undertaking by D. McLeay & Associates Ltd., Norecol Environmental Consultants Ltd., and staff of the Department of Fisheries and Oceans. The study also relied upon the co-operation of placer miners along Highet Creek, within the Minto Creek drainage.

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ABSTRACT

McLeay, D.J., A.J. Knox, J.G. Malick, I.K. Birtwell, G. Hartman and G.L. Ennis. 1983. Effects on Arctic grayling (*Thymallus arcticus*) of short-term exposure to Yukon placer mining sediments: laboratory and field studies. Can. Tech. Rep. Fish. Aquatic Sci. 1171: xvii + 134 p .

A program of controlled laboratory and *in-situ* field bioassays was conducted during 1982/83 to examine the acute effects of suspensions of Yukon placer mining sediment on underyearling Arctic grayling (*Thymallus arcticus*). Wild grayling, captured as swimup fry or young fingerlings, were acclimated to warmwater (15°C) or coldwater (5°C) conditions for 7-12 weeks, and subjected to a range of concentrations of organic sediment (overburden) and/or inorganic sediment (paydirt) suspensions in recirculating test tanks. On two occasions (August and September 1982), grayling fingerlings were captured from central Yukon clearwater streams and held for 4 or 5 days in cages within turbid creekwater (Highet Creek) downstream of placer mining activities, and at a nearby clearwater site (Minto Creek upstream of its junction with Highet Creek).

Laboratory-reared grayling acclimated to 15°C survived a 4-day exposure to inorganic sediment suspensions $\leq 250{,}000\ \mathrm{mg \cdot L^{-1}}$, and a 16-day exposure to 50,000 $\mathrm{mg \cdot L^{-1}}$. These fish also survived acute (4-day) exposure to all strengths of organic sediment examined ($\leq 50{,}000\ \mathrm{mg \cdot L^{-1}}$). All fish acclimated to 5°C and held in paydirt suspensions $\leq 10{,}000\ \mathrm{mg \cdot L^{-1}}$ survived for 4 days, whereas 10-20% mortalities occurred in the higher strengths examined.

Inorganic sediment strengths $\geq 10{,}000\ \mathrm{mg \cdot L^{-1}}$ caused fish to surface, a direct response to elevated sediment levels. No other behavioural anomalies were evident. Other signs of fish distress or damage were not observed for any grayling surviving exposure to either sediment type. The gill histology of fish surviving these 4-day exposures was normal.

The tolerance of laboratory-reared grayling to temperature extremes (critical thermal maxima) was not impaired appreciably by either sediment type. Slight but consistent declines in critical thermal maxima were noted for warmwater-acclimated fish held in inorganic or organic sediment strengths $\geq 500\ \mathrm{mg \cdot L^{-1}}$ and $\geq 5{,}000\ \mathrm{mg \cdot L^{-1}}$, respectively, whereas changes in thermal tolerance were not found for fish acclimated to cold water and held in high strengths of inorganic sediment.

The acute tolerance of warmwater- or coldwater-acclimated fish to hypoxic conditions (oxygen deficiency) in sealed jar bioassays was not impaired by suspended sediment. Tests with overburden suspensions showed a decreased time to death in these bioassays, which was attributed to the sediment's oxygen demand. High concentrations of paydirt increased time to death (decreased respiratory rate) in sealed jar bioassays for the warmwater-acclimated fish only.

Suspensions of inorganic and organic sediment caused acute stress responses (elevated and/or more varied blood sugar levels, depressed leucocrit levels) for grayling acclimated to either temperature. Responses were noted for sediment

strengths as low as 50 mg·L^{-1} (overburden), although confirmation of threshold-effect levels requires further studies. Hematocrit values for these fish were not affected by sediment.

Acute (short-term) effects toward Arctic grayling of the reference toxicant pentachlorophenol were examined in laboratory biossays. Median lethal concentrations were similar to those found previously with this aquatic contaminant and other species of salmonid fish, and were not affected by acclimation temperatures. The effects on grayling of sublethal strengths of pentachlorophenol noted for temperature tolerance tests, sealed jar bioassays and acute stress bioassays were also similar to those determined before with other juvenile salmonids.

During the August field bioassays, all grayling held in Highet Creek (suspended solids $\leq$100 mg·L^{-1}) or Minto Creek (suspended solids $\leq$20 mg·L^{-1}) for 4 days survived, with no overt signs of distress or physical damage. In September, all fish captured from Minto Creek and held in cages within Highet Creek (suspended solids $\leq$1,210 mg·L^{-1}) or Minto Creek (suspended solids $\leq$34 mg·L^{-1}) for 5 days also survived. Gill tissues of fish sampled in September from cages at each site showed moderate-to-marked hypertrophy and hyperplasia of lamellar epithelium, together with a proliferative number of gill ectoparasites. No histopathological differences were found between sites. The gill histology of uncaged grayling sampled directly from Minto Creek upstream of Highet Creek was normal, although occasional ectoparasites were observed.

All grayling captured from Mud Creek (a clearwater tributary of Minto Creek) and held for the same 5-day period during September in cages within Minto Creek survived; whereas 16% (5 of 32 fish) of the Mud Creek fish held at this time in Highet Creek, died within 96 h. The cause of these deaths was attributed to an intolerable stess loading imposed by the combined effects of fish capture, transport, confinement and exposure to suspended sediment and temperaure fluctuations within Highet Creek.

Although hematocrit values measured for fish caged at either site were similar, mean plasma glucose values for fish held for 4 days within Highet Creek during August were elevated 30% from values for fish caged in Minto Creek at this time. During September, grayling captured from either Minto Creek or Mud Creek and caged in Highet Creek showed a 100% increase in mean plasma glucose levels, relative to values for corresponding groups held in Minto Creek. These differences were thought to be caused by the more stressful water quality conditions (suspended sediment loadings and/or more extreme temperature differences) within Highet Creek, compared with the Minto Creek site.

It was concluded that the short-term exposure of Arctic grayling to sublethal concentrations of suspended inorganic or organic sediment can cause a number of effects including acute stress responses. In light of these findings, the environmental impact of placer mining sediments on the immediate and long-term adaptive capabilities (including feeding and other behavioural responses, disease resistance, growth and chronic well-being) of this sensitive fish species needs to be more fully understood.

RÉSUMÉ

McLeay, D. J., A. J. Knox, J. G. Malick, I. K. Birtwell, G. Hartman, and G. L. Ennis. 1983. Effects on Arctic grayling (Thymallus arcticus of short-term e4xposure to Yukon placer mining sediments: Laboratory and field studies. Can. Tech. Rep. Fish. Aquat. Sci. 1171: xvii + 134 p.

Le présent rapport porte sur un programme de bio-essais contrôlés en laboratoire et sur le terrain menés en 1982-1983 afin d'étudier les effets aigus de sédiments en suspension provenant de l'exploitation de gisements alluvionnaires au Yukon sur des individus de moins d'un an d'ombre arctique (Thymallus arcticus). Des ombres sauvages, capturées au stade d'alevins nageurs ou jeunes digitales, ont été acclimatées à l'eau chaude (15°C) ou froide (5°C) pendant 7 à 12 semaines et soumises à une gamme de concentrations de sédiments organiques (morts-terrains de recouvrement) et inorganiques (riches graviers aurifères) en suspension dans des bassins d'essai à renvoi. Des digitales ont été prises dans des ruisseaux d'eau claire du Yukon central, soit en août et en septembre, et maintenues pendant 4 ou 5 jours dans des cages placées dans l'eau turbide du ruisseau Highet en aval de l'exploitation minière alluvionnaire et dans l'eau claire du ruisseau Minto, en amont de sa jonction avec le ruisseau Highet.

Les ombres élevées en laboratoire et acclimatées à 15°C ont survécu à une exposition de 4 jours à des sédiments organiques en suspension $\leq$250 000 mg.L^{-1} et de 16 jours à 50 000 mg.L^{-1}. Ces poissons ont aussi survécu à une exposition aiguë (4 jours) à toutes les concentrations de sédiments organiques testées ($\leq$50 000 mg L^{-1}). Tous les individus acclimatés à 5°C et gardés dans des suspensions d'alluvions exploitables $\leq$10 000 mg.L^{-1} ont survécu pendant 4 jours alors que la mortalité variait de 10 à 12 % en présence de concentrations plus élevées.

Des concentrations de sédiments inorganiques $\geq$10 000 mg.L^{-1} forçaient les poissons à faire surface, ce qui représente une réaction directe à des niveaux élevés de sédiments. Aucune autre anomalie de comportement n'a été notée. Aucun signe d'épuisement ou de dommage n'a été remarqué chez les ombres qui ont survécu à une exposition aux deux types de sédiments. Les préparations histologiques des ouïes de poissons après 4 jours d'exposition ne révélaient aucune anomalie.

La tolérance des ombres élevées en laboratoire aux extrêmes thermiques (maximums thermiques critiques) n'a pas été grandement diminuée par les deux types de sédiments. Des baisses faibles mais constantes des maximums thermiques critiques ont été notées chez les poissons acclimatés à l'eau chaude et maintenus dans des concentrations de sédiments organiques et inorganiques $\geq$500 mg.L^{-1} et $\geq$ 5 000 mg.L^{-1} respectivement alors que des variations de la tolérance thermique n'ont pas été découvertes chez les poissons acclimatés à l'eau froide et maintenus dans des concentrations élevées de sédiments inorganiques.

La tolérance aiguë des poissons acclimatés à l'eau chaude et froide aux conditions hypoxiques (carence d'oxygène) pendant des bio-essais menés dans des bocaux scellés n'a pas été réduite par les sédiments en suspension. En présence de suspensions de morts-terrains de recouvrement, la mort était plus rapide à cause de la demande en oxygène des sédiments. Des concentrations élevées d'alluvions exploitables retardaient la mort (taux de respiration abaissé) des poissons acclimatés à l'eau chaude seulement.

Des suspensions de sédiments inorganiques et organiques causaient des réactions de stress aigu (niveaux de sucre sanguin élevés ou plus variables et niveaux abaissés de leucocrites) chez les ombres acclimatées aux deux températures. Les réactions aux concentrations de sédiments aussi faibles que 50 $mg.L^{-1}$ (morts-terrains de recouvrement) ont été notées quoique une confirmation des niveaux de seuil requière des études plus poussées. Les valeurs de l'hématocrite chez ces poissons n'étaient pas affectées par la présence de sédiments.

On a aussi étudié l'incidence aiguë (à court terme) d'une substance toxique étalon, le pentachlorophénol, sur l'ombre arctique au cours de bio-essais en laboratoire. Les concentrations létales médianes de ce contaminant aquatique, semblables à celles notées précédemment chez d'autres espèces de salmonidés, n'étaient pas touchées par les températures d'acclimatation. Les effets de concentrations sublétales de pentachlorophénol sur les ombres, notés pendant des tests de tolérance thermique, des bio-essais en bocaux scellés et des analyses biologiques du stress aigu, étaient semblables à ceux déterminés auparavant chez d'autres salmonidés juvéniles.

Pendant les bio-essais sur le terrain menés en août, toutes les ombres gardées dans le ruisseau Highet (solides en suspension $\leq$100 $mg.L^{-1}$) et le ruisseau Minto (solides en suspension $\leq$20 $mg.L^{-1}$) pendant 4 jours ont survécu sans signes évidents d'épuisement ou de dommage physique. En septembre, tous les poissons capturés dans le ruisseau Minto et maintenus dans des cages dans le ruisseau Highet (solides en suspension $\leq$1 210 $mg.L^{-1}$) ou le ruisseau Minto (solides en suspension $\leq$34 $mg.L^{-1}$) pendant 5 jours avaient aussi survécu. Des échantillons d'ouïes de poissons recueillis en septembre dans les cages de chaque site indiquaient une hypertrophie variant de modérée à marquée et une hyperplasie de l'épithélium lamellaire, en plus d'une prolifération numérique des ectoparasites des ouïes. Il n'y avait aucune différence histopathologique entre les deux endroits. Les préparations histologiques d'ouïes d'ombres en liberté capturées dans le ruisseau Minto en amont du ruisseau Highet étaient normales quoiqu'on ait relevé la présence occasionnelle d'ectoparasites.

Toutes les ombres prises dans le ruisseau Mud (un tributaire d'eau claire du ruisseau Minto) et maintenues dans des cages dans le ruisseau Minto pendant la même période de 5 jours en septembre ont survécu tandis que 16 % des poissons (5 sur 32) du ruisseau Mud maintenus pendant ce temps dans le ruisseau Highet sont morts en moins de 96 h. On attribue cette mortalité à une charge intolérable de stress découlant des effets combinés de la capture, du transport, de la mise en captivité et de l'exposition à des sédiments en suspension et à des variations de température dans le ruisseau Highet.

Quoique les valeurs d'hématocrite quantifiées chez les poissons en cage aux deux sites étaient semblables, les valeurs moyennes du glucose dans le plasma chez les poissons maintenus pendant 4 jours dans le ruisseau Highet en août étaient de 30 % supérieures à celles des spécimens gardés dans le ruisseau Minto au même moment. En septembre, des ombres capturées dans les ruisseaux Minto et Mud et mises en cage dans le ruisseau Highet ont subi une augmentation de 100 % des niveaux moyens de glucose dans le plasma par rapport aux valeurs du groupe correspondant gardé dans le ruisseau Minto. On croit que ces différences tiennent aux conditions aquatiques plus stressantes (charges de sédiments en suspension et différences de température plus prononcées) dans le ruisseau Highet par rapport au ruisseau Minto.

On conclut que l'exposition à court terme de l'omble arctique à des concentrations sublétales de sédiments organiques ou inorganiques en suspension peut causer un certain nombre d'effets y compris des réactions de stress aigu. Tenant compte de ces découvertes, il est nécessaire de mieux comprendre l'incidence environnementale des sédiments provenant d'exploitation de gisements alluvionnaires sur les capacités d'adaptation immédiate et à long terme (y compris l'alimentation et les autres réactions de comportement, la résistance aux maladies, la croissance et le bien-être chronique) de cette espèce de poisson sensible.

INTRODUCTION

Placer mining activity in Yukon Territory has increased appreciably during the past few years. The exact impact of current and past mining operations on the fisheries resources in the Pacific and Yukon Region is not clearly understood; however, recent studies have shown site-specific evidence of damage to aquatic life and habitat (Mathers et al. 1981; Singleton et al. 1981; Weagle 1982).

Adverse effects attributed to suspended and deposited sediment loads in receiving waters downstream of placer mining activities include degraded water quality (Knapp 1975; Anon. 1981; Mathers et al. 1981); reduced numbers of benthic invertebrates (Anon. 1979a; Mathers et al. 1981); habitat disruptions and reduced numbers of Arctic grayling (Thymallus arcticus) and other fish species (Knapp in prep.; Anon. 1979; Weir 1979; Mathers et al. 1981; Singleton et al. 1981; Weagle 1982). Despite this evidence of threat to Yukon fisheries, present data concerning direct evidence for the deleterious effects of suspended sediment on grayling and other sensitive aquatic species native to these waters are insufficient to permit a clear understanding of the impact of placer mining sediments on Arctic grayling.

Earlier studies (Herbert and Merkens 1961; Anon. 1965; Neumann et al. 1975; O'Connor et al. 1977; Noggle 1978) have reported that sediment suspended in water can cause acute lethal or sublethal effects toward fish. Although some non-salmonid fish species have been shown to survive short-term exposures to suspended sediment strengths as high as 100,000 $mg \cdot L^{-1}$ (Wallen 1951), bioassays conducted by Noggle (1978) indicated that salmonid fish tolerance to natural stream sediment varied seasonally and that suspended sediment concentrations as low as 1,200 $mg \cdot L^{-1}$ could be acutely lethal to underyearling salmonid fish. Additionally, Noggle's (1978) findings demonstrated that lower sediment strengths could be stressful to these fish.

The present studies were undertaken to provide an understanding of the acute lethal tolerance of Arctic grayling to placer mining sediment under both laboratory and field conditions; and to determine if short-term exposures to sublethal sediment strengths caused certain deleterious effects (gill histopathologies, impaired respiratory capacity, reduced tolerance to temperature extremes, stress responses) to these fish. The influence on these responses of differing sediment types (inorganic "paydirt" fines and organic "overburden" soil) found suspended in stream water as a result of placer mining activities (Anon. 1981; Emond 1982), and of seasonal changes in photoperiod and water temperature to which Arctic grayling were acclimated, were also examined in laboratory tests. The acute lethal and sublethal responses of laboratory-reared grayling to the reference toxicant pentachlorophenol (Davis and Hoos 1975) were determined in concurrent bioassays in order to relate the nature and extent of effects to those ascertained for other salmonid fish species with this contaminant.

The acute bioassay tests to which these grayling were subjected were based upon procedures developed previously for evaluating the short-term impact toward salmonid fish of a variety of aquatic contaminants or other environmental stressors (McLeay and Gordon 1980; Wedemeyer and McLeay 1981). As part of this investigation, short-term in-situ bioassays were conducted on each of two occasions (August and September 1982) with wild underyearling grayling held captive in a Yukon clearwater stream (Minto Creek), and in a tributary stream (Highet Creek) downstream of active placer mining. It was hoped that these laboratory and field studies would provide a better understanding concerning the direct effects of placer mining sediments on the acute tolerance and short-term adaptive capabilities of juvenile Arctic grayling.

MATERIALS AND METHODS

LABORATORY STUDIES

Fish collection

A heterogeneous population of approximately 5,000 young-of-the-year Arctic grayling were collected from northern British Columbia waters within the Yukon River drainage basin during July and August, 1982. These fish, captured by seining, ranged in size from 1.5 cm (0.03-g swimup fry) to 5.0 cm (1-g young fingerlings), depending on collection site and time.

Upon capture, fish were placed in plastic "laundry" baskets lined with fibreglass mesh screen, and held in the stream from which they were seined until sufficient numbers (800-1,000) were collected for shipment. Groups of 50-100 individuals were placed in creekwater within 20-L plastic bags, and provided with an oxygen atmosphere (cylinder O_2). These water bags were placed in coolers and packed with ice at the earliest opportunity. Fish were trucked to Whitehorse (Yukon Territory) and air-expressed to Vancouver for the controlled laboratory bioassays. A total of five separate shipments were made.

Fish rearing

Upon receipt at the Vancouver laboratory (B. C. Research), fish were transferred to an outside fibreglass hatchery trough (swimup fry) or to four outside 1000-L semicircular fibreglass tanks (fingerlings). Water supply to these tanks was Vancouver City dechlorinated tap water, heated and regulated to a constant temperature of $15^{\circ} \pm 1^{\circ}C$. The minimum water exchange rate to each tank was 2 $L \cdot g^{-1}$ fish per day throughout the duration of this study. Additionally, fish-loading density in each tank was held below 2.5 $g \cdot L^{-1}$ to ensure that grayling were not overcrowded (Sprague 1973).

Initially, fish were fed Biodiet No. 1 (0.6 mm crumble size; Bioproducts Inc., Warrenton, Ore.) supplemented with live brine shrimp. Food was offered 8-10 times daily, and trough/tanks siphoned daily to remove excess food and faeces. Due to difficulties encountered in encouraging the younger (swimup fry) grayling to feed, the trough-reared fish were also offered finely-ground beef heart, freeze-dried pulverized tubifex worms, live daphnia (*Daphnia pulex*), Oregon Moist mash and canned salmon.

Feed crumble size was increased to 0.6-0.8 mm (Biodiet NO. 2) during late August. This ration was gradually replaced with Oregon Moist pellets (OMP; 1.6 mm) supplemented with twice-weekly feeds of live brine shrimp.

Fish were size-sorted and transferred to clean tanks at 4 to 6 week intervals. Water temperature to which these fish were acclimated was maintained at 15° ± 1°C until December 1 (i.e. until all bioassays with 15°C-acclimated fish were completed). At this time, the water temperature within each of three outdoor tanks holding the remaining stock of grayling was decreased gradually ($2^{o}C\ day^{-1}$) using increasing flow rates of untempered (5° ± 0.5°C) Vancouver City dechlorinated tap water, until this colder temperature was attained. Grayling were acclimated to this water temperature for a 7-week period prior to the final series of bioassay tests. Throughout this period, fish were fed twice daily an excess ration of OMP together with freshly thawed sockeye salmon (*Oncorhynchus nerka*) eggs.

Sediment collection

A 200-kg sample of inorganic sediment was collected from a Highet Creek placer mine site on August 10, 1982. This sample was coarse-screened on-site from a seam of near-bedrock material being actively sluiced, and particle sizes ≤2 mm retained. The nature of this sediment was characteristic of that commonly referred to by placer miners as "paydirt" (Emond 1982). The sample was transported to Vancouver in new 20-L sealed plastic buckets, whereupon it was mixed thoroughly (240-L plastic barrel), returned to the buckets and stored at 4°C until required for bioassay tests.

A sample of organically-rich overburden material weighing approximately 200 kg was obtained during August from a site alongside Minto Creek where the vegetation had recently been stripped away. This dark-brown "muck" (80% moisture content) was also transported to the Vancouver laboratory in new (sealed) 20-L plastic pails. The sample was mixed in a 240-L plastic barrel, returned to pails and stored in the dark at 4°C until required for testing.

Sediment preparation and analyses

Preliminary examination of the inorganic paydirt material indicated that the majority (>98%) of this sample was comprised of particles >1.0 mm (i.e. too coarse for the present study). Accordingly, a procedure was derived which reduced the sample to sediment fines. Quantities of paydirt required for each bioassay test were oven-dried (50°C) to constant weight. Measured amounts (200 ml = 280 g) were then pulverized for exactly 2 min using a vibratory ring pulverizer (TMS

Engineering, Vancouver). Aliquots of pulverized paydirt were combined and stored in polyethylene bags until used.

Preliminary tests with the organic muck indicated that wet sieving or fine screening of this material to select particle fines was difficult and impractical. Quantities required for each bioassay test were therefore coarse-screened only to remove rootlets and woody debris from the humic soil. This pre-sorted undried organic overburden material was held in covered plastic beakers until used for the bioassay tests.

Portions of each of these two prepared sediment types were analysed for the following characteristics: particle size distribution; particle shape; moisture content; volatile and fixed residue; rate of oxygen uptake; and major and trace inorganic components.

Two 280-g samples of paydirt (sub-samples of portions prepared for the 4-day survival tests and stress bioassays) were examined for particle size distribution. Each sample was wet-sieved, oven-dried (50°C) and mechanically agitated for 10 min through a standard series of Tyler sieves. Percentage weight of paydirt retained on each sieve was calculated (Anon. 1972).

A 300-g portion of coarse-screened organic muck was wet-sieved in 50-g increments. The oversized (+400 mesh) material retained was then oven-dried (50° C) and rolled out with a stainless steel rolling pin (to break conglomerates). The resulting material was mechanically agitated (10 min) through sieves, and calculations made of the percentage weight retained on each.

The appearance of each sediment type was examined microscopically. Both dry and wet (suspensions in water) preparations were viewed under dissecting (50X) and compound (400X) microscopes.

Moisture content of each test material was determined by drying 500-g portions at 105°C to constant weight. Their volatile and fixed components were ascertained by igniting each sample at 550°C to constant weight (Anon. 1980a).

The oxygen uptake rate at 15°C for each sediment type was measured according to a procedure used previously (Anon. 1979b) for evaluating dredged sediments. Fixed volumes (30 ml) of material were added to 500-ml Erlenmeyer flasks containing 500 ml of oxygen-saturated freshwater (Vancouver City dechlorinated tap water) at 15°C. Each flask was stoppered, shaken and allowed to remain undisturbed for 24 h at this temperature. Initial and final dissolved oxygen values for the overlying water were measured (Delta Scientific Model 1010 portable oxygen analyser with mechanical agitator) and oxygen uptake rates calculated.

The major and trace inorganic constituents of each test material were determined by plasma spectrographic analysis. Dried (105°C) preparations were digested using a combination of acids (HF, HCl, HNO_3, $HClO_4$) and the resulting solutions analysed for metals using an inductively coupled argon plasma spectrograph (Can Test Ltd., Vancouver, B. C.).

The interrelationship of nonfiltrable residue (suspended solids), total residue and turbidity values for suspensions of each sediment type in freshwater was examined. A range of concentrations (nominally 0-50,000 mg sediment$\cdot$L^{-1}, dry weight basis) of paydirt or overburden material in freshwater (Vancouver City dechlorinated tap water) was prepared using separate 1-L plastic bottles. Aliquots (100-ml volume) were taken from each bottle for determinations of total nonfiltrable residue, total residue, and turbidity (formazin turbidity units - FTU). Each aliquot was taken immediately after vigorous agitation of the sample bottle. Aliquots for turbidity analyses were re-agitated just prior to examination. All analyses were performed according to Standard Methods (Anon. 1980a).

Recycle test tanks

Thirty 50-L capacity recycle test tanks were constructed for use in the acute survival bioassays, temperature tolerance tests and stress bioassays. The basic design for each tank was according to Noggle (1978). The body of each tank, made of 6-mm translucent plexiglass sheeting (transparent sheets sand-blasted to reduce visual disturbances to fish in clear solutions), measured 41 X 37 X 36 cm. A steeply sloping conical-shaped bottom ensured that all settleable solids would be collected and re-circulated. During operation, the test suspension in each tank was withdrawn continuously from this cone through a pump (Little Giant Model 1-42) at a rate of 10.3 ± 0.3 L$\cdot$min^{-1} (mean ± SD; n = 20), and respilled onto the surface of the suspension (see Fig. 1).

A rectangular fish basket, made of soft-mesh nylon netting framed with stainless steel rods, was constructed to fit the body of each tank. These baskets were used to contain fish and to raise them for periodic observations or for sampling.

Bioassays using these tanks were conducted in a temperature-controlled room removed from general laboratory disturbances. Overhead incandescent lighting, regulated by photocell, provided a natural photoperiod for all tests. Lights were brightened/dimmed gradually (30-min automated rheostat) at the start and end of each daily cycle to simulate natural conditions.

Acute survival tests

Fish acclimated to 15°C

A study was conducted to determine fish mortalities and gill histopathologies associated with acute (up to 4-day) exposure to suspensions of paydirt or overburden sediment fines. Five underyearling grayling acclimated to laboratory water at 15°C for 7 weeks were placed randomly in each of a series of 50-L volumes of these suspensions within the recycle test tanks. Nominal strengths (dry weight basis) of paydirt to which these groups were exposed ranged from 50 to 250,000 mg sediment$\cdot$L^{-1}, and from 50 to 50,000 mg$\cdot$L^{-1} for the overburden suspensions. Each suspension was prepared by mixing a pre-weighed amount of test material into the tank while the freshwater was re-circulated. Vancouver City dechlorinated tap water (at 15°C) was used for preparing all suspensions and as the control water (no sediment added). Overhead airconditioning was regulated to hold the temperature of each suspension within values to which these fish were acclimated.

Initial tests with the suspensions of overburden indicated that nominal strengths 10,000 or higher (dry weight basis) fouled the pumps. Consequently, agitation of these higher organic sediment strengths was maintained by upwelling compressed air through the apex of the conical bottom of each of these test vessels.

Water temperature, pH, dissolved oxygen content (mg $O_2 \cdot L^{-1}$) and conductance (umho$\cdot$cm^{-1}) values for each suspension were monitored daily throughout a 96-h test period, together with fish survival and behavioural observations (surfacing, coughing, swimming activity). Upon completion of this period of exposure, surviving fish in each test suspension were netted sequentially and their fork length (cm) and wet weight (g) determined. The caudal peduncle of each fish was severed, and blood collected in heparinized microhematocrit glass capillary tubes. All blood samples from each group of fish were collected within 5 min. Blood samples were centrifuged (12,500 rpm; 3 min) and hematocrit values (Fig. 2) measured. Plasma portions were separated and stored frozen (-20°C) until analysed (10 uL aliquots) for glucose content (Beckman Glucose Analyser 2).

Gill tissue was dissected from each fish and placed immediately in Bouin's fixative. These tissues were transferred 24 h thereafter to 95% ethyl alcohol. Subsequently, select groups of these tissues (gills from three fish held in 0, 100, 1,000, 10,000, and 100,000 mg$\cdot$L^{-1} paydirt or 0, 100, 5,000 and 50,000 mg$\cdot$L^{-1} overburden) were paraffin-embedded, sectioned (6 um) and stained (hematoxylin/eosin) for histopathological examination.

A 100-ml aliquot of each test suspension was taken from the end of the pump outlet tube (paydirt suspension) or from the centre of the tank (overburden suspensions) at the termination of the 4-day fish survival tests. These aliquots were dried and analysed for total residue content (Anon. 1980a). Results were expressed as final suspended residue concentration (mg sediment$\cdot$L^{-1}).

Upon completion of the 4-day exposure tests with grayling and paydirt suspensions, ten hatchery-reared rainbow trout (Salmo gairdneri) swimup fry (0.5 ± 0.1 g; 3.4 ± 0.3 cm) were added to each test suspension within the recycle test tanks. These fish were acclimated to Vancouver City dechlorinated tap water since their receipt as eyed eggs. The survival of these salmonid fish was monitored daily throughout a subsequent 4-day period of exposure.

Exposure of one group of Arctic grayling to a high strength of suspended paydirt fines (50,000 mg$\cdot$L^{-1}) was continued for a total of 16 days, during which time daily observations of fish were made. This suspension was recycled continuously throughout the 16-day test period, and water temperature was held at 15° ± 1°C.

A final group of five grayling acclimated to 15°C was examined for 4-day survival in a high (100,000 mg$\cdot$L^{-1}) concentration of suspended paydirt prepared by sieving only (no pre-grinding). Sediment used for this test was that portion of dried material which passed through an 0.5 mm pore sieve. A sample of this sieved test material was analysed for particle size distribution.

Fish acclimated to 5°C

The acute tolerance of 5°C-acclimated Arctic grayling to suspended paydirt fines was examined under controlled laboratory conditions. Groups of ten fish held previously at 5° ± 1°C for seven weeks were transferred from the outside holding tanks to separate recycle test tanks containing 50 L of inorganic suspensions ranging in concentration from 500 to 100,000 $mg \cdot L^{-1}$. Fish survival, water temperature, pH, conductance and dissolved oxygen content in each tank were monitored daily throughout a 4-day period of exposure. Overhead airconditioning was adjusted to maintain the water temperature in each test tank within the range to which these fish were acclimated (5° ± 0.5°C). Other conditions and procedures were according to those described previously.

Following a 96-h exposure, individual fish surviving in each test suspension were netted rapidly (within a 7-min period). Lengths and weights were recorded, and blood samples collected and processed (as described previously) for hematocrit, leucocrit (see Fig. 2) and plasma glucose determinations.

The consistency with which differing strengths of inorganic sediment remained suspended within the recycle test tanks was examined during this 4-day test. Aliquots (100 ml) of each suspension were withdrawn from the centre of each tank for total residue analyses at each of the following times after their introduction: 0, 0.5, 5, 24, 48, 72 and 96 h. Additional aliquots were taken from each tank at 48 h in order to assess the dispersal pattern for each recirculating suspension. These samples were taken from each tank at the following locations: inflowing suspension (end of pump outlet tube); surface (centre of tank); mid-depth (centre of tank); and near a bottom corner of the net enclosure. Each aliquot was analysed for total residue concentration (Anon. 1980a).

Temperature tolerance tests

Fish acclimated to 15°C

The effect of suspended paydirt or overburden material on the critical thermal maxima (upper lethal temperature tolerance) for underyearling Arctic grayling acclimated to 15°C (for 9 weeks) was determined in separate studies. Basic test procedures for this bioassay were according to those described previously (McLeay and Howard 1977; McLeay and Gordon 1980).

Ten grayling were transferred randomly to each 50-L test suspension within each of a series of recycle test tanks. Test apparatus and procedures for preparing each suspension were identical to those given for the acute survival tests. Nominal concentrations of inorganic paydirt to which fish were exposed ranged from 25 to 100,000 $mg \cdot L^{-1}$, and from 50 to 50,000 $mg \cdot L^{-1}$ for the organic overburden.

The temperature of each test suspension was initially 15°C. This temperature was increased progressively at a controlled rate of $1^{o}C \cdot h^{-1}$ (electric baseboard heaters coupled with a thermostatically-controlled immersion heater in each tank) until all fish in each tank were dead. The temperature of each test suspension was recorded ($\pm$ 0.1°C) at the time of death of each fish. These fish were removed and measured (length, weight). Aliquots of each suspension were then taken from the centre of each test vessel for analyses of final suspended residue content.

Fish acclimated to 5°C

The effect of paydirt suspensions on the critical thermal maxima for grayling acclimated to 5°C for 9 weeks was examined. Groups of ten fish were transferred from a rearing tank to recycle test tanks containing nominal paydirt suspensions ranging from 100 to 50,000 $mg \cdot L^{-1}$. The temperature of each test suspension was initially 5°C, and was increased at $1^{o}C \cdot h^{-1}$ until all fish were dead. Other test procedures and conditions were identical to those used for the temperature tolerance tests conducted with 15°C-acclimated grayling.

Sealed jar bioassays

Fish acclimated to 15°C

Sealed jar (residual oxygen) bioassays were conducted with juvenile grayling acclimated to 15°C for 12 weeks. Basic test procedures were those developed for use with kraft pulpmill effluents (McLeay 1976; Gordon and McLeay 1977) and applied subsequently with other aquatic contaminants (McLeay and Gordon 1980).

Grayling weighing approximately 10 g were selected for these bioassays. The sealed jar tests were conducted at 20°C using 1.9-L glass jars, one fish per jar (fish-loading density, $5\ g \cdot L^{-1}$) (McLeay 1976).

For each concentration of paydirt or overburden examined, ten replicate jars were prepared (identical weights of sediment added to each). Two replicate sets of ten control solutions (freshwater only) were included with each series of sealed jar tests conducted with paydirt or overburden sediments. Air-saturated freshwater (Vancouver City dechlorinated drinking water) at 20°C was added to each jar and the fish introduced. Each jar was then filled completely with water, and sealed (plastic lid) to exclude air.

Each jar was inverted at 20- to 30-min intervals throughout the test period in order to re-expose fish to any settleable solids. Control jars (freshwater only) were treated accordingly. The survival or death of fish was determined on these (and more frequent) occasions. Upon the death of each fish, water temperature and time to death were recorded. The residual oxygen level in each suspension was measured using a portable oxygen meter (Delta Scientific Model No. 1010) with mechanical agitator.

The initial (maximum) and final (minimum) suspended residue concentrations to which fish were exposed during these tests were determined. At the time of the bioassays, one additional jar containing each test suspension was prepared, and a 10-g fish added. Upon the inversion of each jar, an aliquot of each suspension was extracted (by syringe) from the jar's centre. This procedure was repeated after the jar was left undisturbed for 30 min. Each aliquot was analysed for total residue concentration.

Fish acclimated to 5°C

Underyearling grayling acclimated to 5°C freshwater for 11 weeks and weighing approximately 10 g were selected for this study. Sealed jar bioassays with differing strengths (100-100,000 $mg \cdot L^{-1}$) of suspended paydirt fines were conducted at 10°C, using air-saturated freshwater adjusted to this temperature overnight as the control or test (dilution) water to which fish were exposed. Otherwise, test apparatus and procedures used for this bioassay were identical to those employed in the previous sealed jar test with grayling and paydirt.

Acute stress bioassays

Controlled bioassays were performed to determine the concentrations of paydirt and overburden suspensions which are acutely stressful to Arctic grayling. Basic test procedures were those proven effective for determining threshold strengths of a variety of aquatic contaminants which cause stress responses (elevated blood sugar levels, decreased numbers of circulating leucocytes) with other salmonid fish species (McLeay 1977; McLeay and Gordon 1977, 1979, 1980).

Groups of ten underyearling grayling acclimated to 15°C for 12 (overburden bioassays) or 13 weeks (paydirt bioassays) were transferred from the outside tanks to a series of indoor recycle tanks containing freshwater (at 15°C) only. Fish were left undisturbed in these tanks for a 48-h period in order to adapt to the stress caused by this transfer. Thereafter, weighed portions of paydirt or overburden sediment were added to each tank at 20-min intervals. Tanks for each treatment were chosen randomly. For each test (paydirt or overburden material), two tanks were selected as controls. Nominal concentrations of paydirt to which these fish were exposed ranged from 50 to 100,000 $mg \cdot L^{-1}$, and from 50 to 20,000 $mg \cdot L^{-1}$ for fish held in suspensions of overburden material.

Each group of ten grayling was sacrificed for blood sugar and leucocrit determinations after a 24-h exposure to each sediment suspension. The control groups were sampled just prior to and again just subsequent to the sampling of all experimental groups to ensure that no changes in the stress responses measured were caused by sampling disturbance. Sampling procedures and methods for determining plasma glucose, hematocrit and leucocrit values for each fish were identical to those described previously in this report.

Reference toxicant tests

The response of the laboratory-reared Arctic grayling to the reference toxicant pentachlorophenol (Davis and Hoos 1975) was determined at the time that these bioassay tests were conducted. Fresh stock solutions of pentachlorophenol were prepared by dissolving 100 mg dry powder (Aldrich Chem. Co. Inc.; Lot No. 122047; purity >99%) in 10 ml of 2% NaOH, and diluting to 1 L with deionized water (Alderdice 1963). These concentrated stock solutions were diluted ten-fold as required for each bioassay.

The acute lethal tolerance to pentachlorophenol of grayling acclimated to 15° or 5°C was determined just prior to the start of the acute survival tests with paydirt sediment. Groups of ten fish were transferred from stock tanks to 45-L glass aquaria containing pentachlorophenol concentrations (diluted with Vancouver City dechlorinated tap water) ranging from 30 to 120 $ug \cdot L^{-1}$. Test temperature for these static bioassays was held at that to which the grayling were acclimated (15° or 5°C). Fish survival in each test solution was monitored daily throughout a 4-day test period.

The effect of sublethal and lethal concentrations of pentachlorophenol on the upper lethal temperature tolerance of juvenile grayling acclimated to 15°C was ascertained. Groups of ten fish were transferred from a stock tank to recycle test tanks containing pentachlorophenol strengths of 0 (freshwater control), 25, 50 and 80 $ug \cdot L^{-1}$ freshwater. The temperature of each test solution was increased from an initial value of 15°C at a rate of $1^{o}C \cdot h^{-1}$ until all fish died, and the temperature at time of death of each fish determined. Conditions and procedures for conducting this bioassay were identical to those described for the temperature tolerance tests performed with 15°C-acclimated grayling and sediment suspensions.

The effect of pentachlorophenol on the tolerance to hypoxia of 15°C-acclimated grayling was determined by sealed jar bioassay. Materials and methods were those described earlier. Residual oxygen levels at death were determined for fish held in jars containing pentachlorophenol strengths of 0 (two freshwater control groups), 35, 50 and 80 $ug \cdot L^{-1}$.

The effect of sublethal concentrations of pentachlorophenol on acute stress responses for 15°C-acclimated grayling was examined at the time and according to procedures described for the stress bioassays carried out with grayling and sediment suspensions. For these tests, four groups of ten fish were exposed to the following strengths of this reference toxicant for 24 h: 0 (freshwater control), 20, 35 and 50 $ug \cdot L^{-1}$. Plasma glucose, hematocrit and leucocrit values for each of these fish were measured as described previously.

The length (cm) and wet weight (g) of each fish exposed to pentachlorophenol were determined at time of death or upon termination of each bioassay test.

Statistical analyses

The condition factor (K) of juvenile grayling used in each bioassay test was determined as follows: $K = cW \cdot L^{-3}$ where c is a constant (100), W is weight (g) and L represents fork length (cm) (Carlander 1969).

Mean and standard deviation (SD) values for fish length, weight and condition factor were calculated for each bioassay. Mean ± SD plasma glucose, hematocrit and leucocrit values determined for each group of fish receiving identical treatment were also determined. Additionally, mean (± SD) temperatures at death (temperature tolerance and sealed jar tests), times to death and residual O_2 values at death (sealed jar test) were calculated for each control and test group. For values shown graphically, the 95% confidence interval of each mean was determined.

The acute median lethal concentration (96-h LC50 value) for the reference toxicant pentachlorophenol, as determined with groups of juvenile grayling acclimated to 5° or $15^{\circ}C$, was calculated (together with its 95% confidence interval) using the computerized LC50 program of Stephan (1977).

The median effective concentration (EC50 value) of each sediment type causing a net significant response for 50% of the fish treated identically in each bioassay (temperature tolerance test, sealed jar and acute stress bioassays) was calculated according to established procedures (Sprague 1968; McLeay and Howard 1977; McLeay and Gordon 1980). Relevant values determined for each test fish (i.e. temperature at death, temperature tolerance test; time to death and residual O_2 at death, sealed jar bioassay; plasma glucose and leucocrit, acute stress test) were examined to determine the number of responses for each treatment outside of the 95% confidence interval for the corresponding group(s) of control fish. Depending on the suitability of the data derived in this manner the EC50 value for each test was calculated, together with its 95% confidence interval (Stephan 1977).

FIELD STUDIES

Study area

General

The Highet Creek and Minto Creek sites chosen for the in-situ caged fish bioassays were selected following an aerial and ground reconnaissance of some nine creeks in Central Yukon on June 26 and 27, 1982. The study area (Fig. 3) lies in the Selwyn Basin portion of the Canadian Cordillera, and is underlain by sedimentary limestone skarn and quartzite schist rocks of the Windermere Group (Tipper et al. 1982). Quartz is the main mineral in this mineralogically complex rock, although diorite and granitic rock protrudes through the older schists in several areas.

The surficial deposits in the area can be divided into three recognizable types: the upper, post-glacial unit consisting of recent and terrace gravels; the glacial unit consisting of till or glacio-lacustrine silts and sands; and the lowermost pre-glacial unit making up the deep, terrace and high level gravels. Several of these deposits, in particular the deep gravels, glacio-lacustrine silts and sands and the till, are exposed in Highet Creek (Cairnes 1915).

The pre-glacial deep and terrace gravels are the most productive in terms of placer gold. They cover the hummocky bedrock of the valley bottom and are from 3 to 8 metres thick. The lower 2-4 m of the deep gravels are commonly stained with manganese oxide and iron oxide. The black to red oxides occur in the gravel matrix and as a stain on the clast surfaces. Some manganese oxides occur in crystals (Emond 1982).

Glacio-lacustrine silts and sand gravels varying in thickness from 3 to 25 m overlie the pre-glacial gravels. These sediments are usually finely laminated dark grey silt layers interlaid with brown sand. The silts were deposited in a shallow lake that was formed when ice, moving westward up Minto Creek, protruded into the lower part of Highet Creek (Bostock 1939).

The glacial till of Highet Creek varies in thickness from 1 to 4 metres. The gravel contains pebbles of assorted rock types. The matrix is a yellowish brown, silty or gritty clay (Emond 1982). Recent gravels approximately 2 metres thick are found in the lower part of the creek valley. The gravel contains well-rounded pebbles and cobbles that are less than 7 cm in diameter. Trace geochemical analyses indicate that gold, tungsten, chromium, iron, manganese, titanium, zinc and zirconium are the most abundant heavy elements in the Highet Creek gravels. Tin, arsenic, cadmium, and mercury were not detected (Emond 1982).

In the Mayo-McQuesten area, gold was first found on sand bars of the Stewart River in 1883. Prospecting of creeks draining the upland led to the discovery of gold, in 1901, in Duncan Creek. Gold was first discovered on Highet Creek in 1900 by Warren Hiatt. Mining began in 1903 on bench claims on the right limit of the upper part of the creek. Several operators mined gravels in the creek bottom during the period 1916-1946. During this early period, a dredge was worked unsuccessfully on the creek for one season. Since 1960, mining on Highet Creek has consisted of three small individual operations which utilize earth-moving equipment and large sluice boxes. Highet Creek has been one of the leading gold producing creeks in the Mayo-McQuesten area.

Highet Creek

Highet Creek originates on the upland (maximum elevation 1825 m) between the McQuesten and Stewart rivers, and flows to the southwest through a narrow valley into Minto Creek (Fig. 3). Although ungauged, this high gradient stream (elevation change 90 $m \cdot km^{-1}$) likely exhibits a seasonal hydrograph similar to other small creeks subject to placer mining in the Mayo area. In undisturbed creeks, peak flows occur during May and early June in response to snowmelt (Anon. 1980b). However, during the summer months the flows in Highet Creek are regulated, and hence may vary considerably from day to day in response to placer mining activity. Winter freeze-up of this creek usually begins in November and extends to April (Allen and Cudbird 1971).

During the open water period, Highet Creek is frequently turbid due to placer mining and erosion of previously mined sections of the valley. Most of the suspended sediment load carried by the creek from June to October is created by mining operations in the upper third of the valley. In the lower sections of the creek, the suspended sediment load consists of that portion of the mine effluent remaining after passage through several settling ponds located 3.0 km upstream of Minto Creek (Fig. 3).

No information on the former use of Highet Creek by fish is available. A preliminary species abundance/habitat study conducted during the summer of 1982 found only limited numbers of underyearling Arctic grayling within Highet Creek, whereas Minto Creek and other Minto Creek tributaries (Bennett Creek, Mud Creek) contained appreciably larger populations of Arctic grayling and other species of fish (Birtwell et al. 1983).

The site in Highet Creek selected for in-situ caged fish studies was located 0.25 km upstream of the junction with Minto Creek (Fig. 3). Biophysical characteristics determined for this site during these field bioassays are provided in Appendix 1.

Minto Creek

Minto Creek flows eastward into the Mayo River through an upland part of the Yukon Plateau that lies between the Stewart and McQuesten river valleys (Fig. 3). Minto Creek originates at Minto Lake (elevation 685 m) and follows a winding 16-km course into Wareham Lake (elevation 580 m). The stream gradient is generally low (1.5 $m \cdot km^{-1}$), particularly in the upper third where it is further reduced by a series of beaver dams. Although ungauged, Minto Creek likely exhibits a seasonal hydrograph similar to other lake-fed streams in the Mayo area. Peak flows occur shortly after breakup in late May or early June whereas low flow usually occurs in February or March (Anon. 1980b). The valley of Minto Creek is undisturbed with the exception of a site approximately 1.5 km below Minto Lake that was placer mined briefly in 1980.

During the summer months, water in Minto Creek above its confluence with Highet Creek is clear to slightly turbid. Below Highet Creek, Minto Creek water is frequently turbid from June to October each year due to the placer mining activities on Highet Creek.

The control site in Minto Creek selected for the in-situ caged fish studies was 0.5 km upsteam of the junction with Highet Creek, at a location that was similar in stream flow and other characteristics, except suspended solids, to the test site in Highet Creek (Appendix 1). This site was chosen for its clear water and its proximity to the Highet Creek site.

Fish collection

For the in-situ caged fish studies, several hundred wild underyearling Arctic grayling were captured from Minto Creek for August bioassays, or from both Mud Creek (Fig. 3) and Minto Creek for September bioassays. Those fish taken from Minto Creek were collected 0.5-0.8 km upstream of the junction with Highet Creek.

Fish were captured from shallow pools and riffles, using one or more seine nets. Upon netting, fish were placed in plastic holding pens lined with fibreglass screening (allowing free flow of creekwater). All captured fish of suitable size were held for 1 to 2 days in Minto Creek (just upstream of the control site) prior to their transfer to cages.

In-situ bioassays

Test apparatus

Ten net enclosures were used for the *in-situ* bioassays. Each enclosure (30 cm deep by 45 cm diameter) consisted of two aluminum rings covered with soft nylon mesh (4 mm). A drawstring in the mesh at the top of the enclosure could be opened to inspect the fish (Fig. 4).

At each site (Fig. 5 and 6), five enclosures were located adjacent to one another at the upstream end of a pool. Each 50-L enclosure was suspended in the water column, 5 to 10 cm below the surface, between three tubular iron posts (Fig. 4). The position of the posts provided stability and allowed each enclosure to be lifted independently for inspection, while at the same time ensuring free circulation of water.

Water quality

Water samples were collected at both the test site (Highet Creek) and the control site (Minto Creek) during the August and September caged fish tests. Samples (300-400 ml) were collected hourly at each site for the duration of the tests, using an ISCO automatic pump sampler. The sampler's intake port was located within an empty fish cage submerged at each site. Samples were removed every 24 h and stored in plastic bottles within coolers for shipment to the Environmental Protection Service/Fisheries and Oceans laboratory at West Vancouver. The following characteristics were measured for alternate samples collected from each site, using procedures established by Environment Canada and Fisheries and Oceans (Anon. 1979c): total residue; total fixed residue; nonfiltrable residue; total volatile residue; and turbidity (FTU).

The particle size of nonfiltrable residue within Highet Creek was estimated from composite creekwater samples taken during both the August and September test periods. These samples were made by combining one hourly water sample selected at random from each of the test days. Each composite sample was analysed by Soil Analysis Inc. (Vancouver) for particle size distribution, using the pipet method (Anon. 1975).

On seven occasions during the August and September test periods, duplicate grab samples were taken from Highet Creek adjacent to the test enclosures. These samples were collected to coincide with samples being drawn from within the enclosures by the automatic sampler. Analyses included turbidity (FTU), nonfiltrable residue and total residue.

Two or more times daily during each in-situ bioassay, the following variables were measured near the net enclosures at each site: water temperature (°C), pH, and dissolved oxygen (mg $O_2 \cdot L^{-1}$). Water temperature was measured using a mercury thermometer. A portable YSI Model 57 dissolved oxygen meter and a Corning Model 610A pH meter were used for the other field determinations.

Several 150- or 250-ml water samples were collected in polyethylene bottles at the enclosure sites. Samples were collected at the beginning and end of each test period for alkalinity, hardness, Mn, Mg, Na, Ca, Si, and total metals (As, B, Ba, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Sr, Zn, Al, and Fe). Samples not requiring preservation were kept cool for return to the laboratory at the conclusion of each study period. All metals except Hg were preserved with 1 ml of HNO_3; Hg samples were preserved using a solution of H_2SO_4 and $K_2Cr_2O_7$. Analysis of all water samples was performed at the Environmental Protection Service/Fisheries and Oceans' West Vancouver Laboratory, using techniques specified (Anon. 1979c).

Experimental

Short-term (4- to 5-day) in-situ bioassays were conducted at the Highet and Minto Creek sites on each of two occasions - August 6 to 10, and September 10 to 15. These field bioassays were conducted twice to determine the effect, if any, of different water temperature regimes on the acute tolerance of grayling to suspended sediment.

In order to maintain a loading density of approximately 1 $g \cdot L^{-1}$, groups of 14 to 26 fish were selected randomly from the holding pens on each occasion, and transported in plastic pails to each of four net enclosures at each site. The mean density of fish placed in each enclosure was approximately 1 $g \cdot L^{-1}$. During August, each cage received grayling captured from Minto Creek; whereas during the September tests, fish introduced to only two of the four cages at each site were captured from Minto Creek. The remaining two cages at each site on this occasion received Mud Creek fish only.

Fish within each cage were observed hourly for the initial 4-h period, and twice daily (between 0900 and 1100 h, and between 1900 and 2200 h) thereafter until the tests were terminated. Each inspection was carried out by raising the cage until its bottom was just below the surface of the water. Inspections were conducted quickly to minimize stress to fish. Any dead fish observed were removed and examined (including measurements of length and weight). Times to death and frequency (%) of fish mortalities were recorded. Fish in cages were not fed on either occasion.

Upon completion of a 96-h (August bioassays) or 120-h (September bioassays) period of exposure, all surviving fish in each cage were sacrificed. Fish were removed individually from each cage, and their fork length and wet weight determined. Gill arches (third or fourth) were removed from five fish selected randomly from each net enclosure, and mounted on glass slides in polyvinyl lactophenol. These tissues were later examined under dissecting and compound microscopes to detect any gross changes in gill morphology.

For the September bioassays only, gill tissues of five grayling caged in Minto or Highet Creek for five days were removed and placed in Bouin's fixative. Gills from five untested grayling seined from Minto Creek were also taken and preserved upon fish capture. These 15 tissues were subsequently transferred to 70% ethyl alcohol, wax-embedded, sectioned (6 um) and stained (hematoxylin and eosin) according to standard practice. For each specimen, a number of pathomorphological changes involving the gill filaments and lamellae were rated on a scale of 0 (normal) to 4+ (extreme pathology). Each specimen was coded and examined "blind" (without knowledge of treatment) to prevent biases from influencing the ratings assigned.

Blood samples were taken from five fish selected randomly from each cage at the time of these autopsies. Each sample, collected in a heparinized microhematocrit tube, was centrifuged in the field (microhematocrit centrifuge with 12-V battery and power converter), and hematocrit values determined. Plasma portions were separated and stored cool but unfrozen (held on ice) for subsequent glucose analyses. Other procedures for blood collection and analyses were according to those described previously.

Samples of blood were taken from 19 and 30 underyearling grayling captured by seining from Mud Creek (August 9, 1982) and Minto Creek (September 14, 1982), respectively. These samples were taken within 5 min of fish capture. Blood hematocrit and glucose values were determined for each of these fish according to procedures used for caged fish.

RESULTS AND DISCUSSION

LABORATORY STUDIES

Fish growth and condition

All grayling air-expressed to Vancouver were alive and in apparently good condition upon their receipt. Efforts to initiate feeding of those fish received as swimup fry proved largely unsuccessful, resulting in a high rate of mortality. These fish mouthed the Biodiet ration offered, but spit it out. Offerings of other ration types (i.e. live Daphnia pulex or finely-ground beef heart) were also unaccepted by these very small fish. Unlike these findings, the larger fish (0.2-1.0 g) commenced active feeding within one week of their receipt. Biodiet ration no. 1 was consumed vigorously by these fish and mortality rates were low.

Cannibalism of smaller grayling was observed frequently, although size-sorting of surviving fish between the four outdoor rearing tanks appeard to minimize this problem. Fish transferred to these tanks fed actively on the commercial rations offered (Biodiet and, later, OMP). Live brine shrimp was readily taken by the fish. Growth of fish acclimated to the 15°C laboratory water supply (pH 6.8 ± 0.2; conductance, 15.7 ± 1.2 $\text{umho}\cdot\text{cm}^{-1}$; nonfiltrable residue, <0.1 $\text{mg}\cdot\text{L}^{-1}$; residual chlorine, <0.01 $\text{mg}\cdot\text{L}^{-1}$; alkalinity, 4.5 ± 1.3 mg $\text{CaCO}_3\cdot\text{L}^{-1}$; EDTA hardness, 5.0 ± 0.3 mg $\text{CaCO}_3\cdot\text{L}^{-1}$) was rapid, with mean (±SD) weights of 2.4 ± 1.2 g by 6 weeks. The stock tank of larger grayling (sized-selected for the sealed jar bioassays) weighed 10.4 ± 1.3 g at 12 weeks. Mean condition factors determined for groups of 15°C-acclimated grayling sampled from the rearing tanks for bioassay tests were 0.8 to 1.0. These values are typical of those determined for underyearling grayling collected from the Minto Creek drainage (Birtwell et al. 1983).

Upon lowering of the water temperature to 5°C, the remaining stock supply of grayling (divided between three outdoor tanks) ceased to feed. Offerings of OMP and brine shrimp were largely rejected during the subsequent 5-week period. Thereafter, an attempt to promote feeding by introducing freshly thawed sockeye salmon eggs proved successful. Active feeding resumed at this time and continued until the bioassay tests with 5°C-acclimated fish were terminated. Condition factors for grayling at the time of these bioassays were similar to previous values (0.8-0.9). The quality of the 5°C water to which these fish were acclimated was as follows (based on weekly measurements): pH 6.7 ± 0.2; conductance, 14.3 ± 2.2 $\mathrm{umho \cdot cm^{-1}}$; nonfiltrable residue, <0.1 $\mathrm{mg \cdot L^{-1}}$; residual chlorine, <0.01 $\mathrm{mg \cdot L^{-1}}$; alkalinity, 5.3 ± 0.8 mg $\mathrm{CaCO_3 \cdot L^{-1}}$; and EDTA hardness, 6.2 ± 1.2 mg $\mathrm{CaCO_3 \cdot L^{-1}}$.

No behavioural anomalies nor signs of disease were evident within the stock supply of grayling held at 15° or 5°C for the laboratory tests. All fish deaths observed (other than those due to cannibalism) were attributed to starvation.

The acute lethal tolerance (96-h LC50; 95% confidence interval in parentheses) to the reference toxicant pentachlorophenol determined for the laboratory-reared grayling acclimated to 15° or 5°C was as follows:

15°C fish: 67 $\mathrm{ug \cdot L^{-1}}$ (57-77);
5°C fish: 61 $\mathrm{ug \cdot L^{-1}}$ (48-71).

All grayling acclimated to either temperature regime survived a 96-h exposure to pentachlorophenol strengths of 40 $\mathrm{ug \cdot L^{-1}}$ and lower. These LC50 values are within the range of tolerance for this respiratory inhibitor reported previously for populations of healthy hatchery-reared rainbow trout or coho salmon (Oncorhynchus kisutch) fingerlings acclimated to and tested in 10-12°C water with pH and hardness characteristics similar to that used in the present studies (Davis and Hoos 1975; McLeay and Gordon 1980). Results from these bioassays, considered together with the observations of the fish stocks, suggest that the condition and tolerance to aquatic contaminants of the laboratory-reared grayling were typical of healthy populations of young salmonid fish species at the time that each series of bioassay tests with suspended sediments was undertaken.

Various workers have reported difficulties with the artificial propagation of grayling. Davis (1967) indicated that certain early investigators were only able to rear grayling fry to the fingerling stage when fish were supplied with creek water containing natural food. Others (Rawson 1950) reported success with finely ground beef liver or heart, supplemented with goldfish food.

As with the present study, other attempts to initiate feeding under laboratory conditions for Arctic grayling captured in the wild as swimup fry have proven largely unsuccessful (LaPerriere and Carlson 1973; Horler MS, 1980). Part of the problems encountered by these investigators were likely due to the type (and crumble size) of commercial ration offered. Transfer stress associated with the capture and transport of swimup fry may also be implicated, together with any prior history of their feeding in the wild. Young grayling fry are thought to be planktivorous feeders, and their early feeding may be restricted by the relatively large size of food organisms available (Bishop 1971; Schmidt and O'Brien 1982). Since the initial laboratory feeding of wild grayling captured as fry $\geq$ 0.2 g was achieved in the present studies using Biodiet, this commercial ration appears to be adequate for this purpose. However, the use of other (non-commercial) food supplements (i.e. live brine shrimp for 15°C-acclimated fish; sockeye salmon eggs for 5°C-acclimated fish) was also required to maintain feeding vigour.

Characteristics of test sediments

Particle size distributions for the paydirt and overburden sediments used in the laboratory bioassays are given in Table 1. Analytical results for each of the two preparations of paydirt fines were similar. Over 90% of the particles in each inorganic sample examined were <0.2 mm (i.e. fine sand, silt or clay); and approximately 70% of the test material was <0.05 mm (silt and clay). The majority (60-65%) of the inorganic sediment sample to which grayling were exposed was comprised of particles less than 0.038 mm (<38 um) in diameter (Table 1). Unlike this material, approximately 50% by weight of the organic overburden was made up of coarse material (>0.2 mm) and only 3% of this soil sample was very fine particles (<38 um). The remainder (47%) of the overburden contained particle sizes characteristic of fine sand or coarse silt. The particle size distribution of these test sediments is, in general terms, characteristic of overburden material found overlying paydirt gravel and of inorganic fines carried into downstream waters during sluicing operations (Anon. 1981).

Microscopic examination (400X) of the inorganic material indicated that the dry tan-brown sediment formed amorphous particles (electrostatic adhesion) which readily dissociated into minute particles upon addition to water. The dark-brown overburden sample was comprised of a considerable quantity of woody debris interspersed with soil particles of various shapes and sizes (very fine to coarse). Further detail concerning the shapes of these test materials could not be discerned by light microscopy, and scanning electron microscopy was not applied.

Values for moisture content, volatile/fixed residue content and oxygen uptake rate (in freshwater at 15°C) for each test sediment are presented in Table 2. The moisture content for the overburden muck remained at 82-85% throughout the period that this sample was stored. This sample was comprised of 96% volatile (organic) material; whereas the volatile component of the paydirt was only 4% of the dried residue. This difference in organic content is consistent with the appreciably greater oxygen uptake rate determined for the overburden material (Table 2).

The metal content of each test sediment is given in Table 3. These values are presented only for sample "fingerprinting"; and an analysis of metals dissolved (and conceivably biologically available) within freshwater suspensions of these test materials was beyond the terms of reference of this investigation.

Thus the extent to which a high concentration of certain constituents (i.e. the arsenic content of the paydirt sample) may or may not contribute to any biological effects noted for freshwater suspensions of these materials cannot be ascertained from these data.

Figures 7 and 8 illustrate the interrelationship of total residue, nonfiltrable residue and turbidity values for differing strengths of each sediment type suspended in freshwater. For both the inorganic and organic sediments, total and nonfiltrable residue values for each sample were almost identical. These values were highly correlated with sample turbidity, and with nominal concentrations (Fig. 7 and 8).

Results from these analyses indicate that the total residue values determined for suspensions of paydirt or overburden taken during the bioassay tests are good approximations of their total nonfiltrable residue (suspended solids) content. The turbidity values measured for each suspension allow rough calculations (based on total residue determinations) of the turbidities of the test suspensions to which fish were exposed.

The degree to which sediment loadings remained in suspension within the recycle test tanks, throughout a 96-h test period, is illustrated in Figure 9. Total residue values determined for the lowest paydirt strength monitored (500 $mg \cdot L^{-1}$) varied appreciably and showed a trend to decline with respect to time sampled; whereas respective values for the higher strengths monitored (5,000-100,000 $mg \cdot L^{-1}$) were more consistent throughout the 96-h test period. The total residue concentrations measured for each treatment were generally lower than the nominal (pre-weighed) strength of sediment added to each tank (Fig. 9).

Information concerning the dispersal pattern for suspended sediment within the recycle test tanks is provided in Table 4. For each suspension examined, the total residue value for the sample taken from the hose outlet (tank inflow) was appreciably (2-5 times) higher than respective values for samples taken from the surface, mid-depth or bottom locations within the net enclosures where fish were held. For paydirt strengths $\geq 5,000$ $mg \cdot L^{-1}$, total residue values for the surface water were slightly but consistently lower than respective values for samples taken mid-depth or from the bottom of the net enclosure (Table 4). These results indicate that, for each of these test suspensions, a portion of the sediment fines was settling and being recirculated. Since the gradient for suspended solids within the portion of each tank to which fish were confined was small, and since these fish were continuously subjected to the settleable solids, the nominal (pre-weighed) strength of paydirt prepared in each recycle tank should approximate that to which the fish were exposed. However, this may not be true for the lower concentrations (i.e. ≤ 500 $mg \cdot L^{-1}$; Fig. 9) tested in these tanks. In such instances a greater proportion of the sediment fines added may adhere to the netting or tank sides, and therefore be effectively unavailable.

Acute survival and gill histology

All 15°C-acclimated grayling survived a 4-day exposure to each suspended paydirt strength examined, up to and including 250,000 $mg \cdot L^{-1}$ (Table 5). Additionally, the five grayling held in 50,000 $mg \cdot L^{-1}$ for a more prolonged period (16 days) survived this extended exposure. All hatchery-reared rainbow trout fry introduced to these suspensions at the termination of the bioassays with grayling also survived for 96 h.

All grayling held in a 100,000 $mg \cdot L^{-1}$ strength of the sample of paydirt prepared by fine-sieving only (no pre-grinding of test material) survived the 4-day exposure. These fish were active and showed no overt signs of damage at this time. Particle size analysis of the sediment to which this group of fish was exposed indicated that 47% of the sample was coarse sand (>0.2 mm), and that only 22% of the test material was very fine particles (<38 um). Thus, as with the pulverized preparations of paydirt fines examined, this coarser inorganic sediment suspension also permitted acute survival of underyearling grayling.

All grayling acclimated to 15°C and held in organic overburden suspensions up to 50,000 $mg \cdot L^{-1}$ (nominal strength) survived the 4-day test period (Table 6). Those fish acclimated to 5°C and exposed to coldwater suspensions of inorganic paydirt fines up to and including 10,000 $mg \cdot L^{-1}$ also survived for four days; whereas mortalities of 10% (20,000 $mg \cdot L^{-1}$) to 20% (100,000 $mg \cdot L^{-1}$) were found with fish groups held in higher sediment strengths (Table 7). In these instances, fish deaths did not occur until after a 48-h exposure. All control fish examined in each survival test were alive and in apparently good condition throughout the 96-h period of exposure.

Behavioural observations of fish during the acute survival tests were restricted due to the opacity of the suspensions. For the more dilute suspensions of paydirt or overburden permitting these observations (50 and 100 $mg \cdot L^{-}{}_{1}$), no signs of coughing or increased swimming activity were seen.

In both the 5°C and 15°C bioassays with paydirt, grayling held in sediment strengths $\geq$10,000 $mg \cdot L^{-1}$ remained at the surface of each suspension. These fish showed no signs of respiratory distress. In exhibiting this behavioural abnormality, the fish could have been detecting and seeking lower sediment strengths within the surficial waters (Table 4). Surfacing of fish was not apparent in the lower strengths of paydirt examined nor in any concentration of suspended overburden.

Inspection of fish at time of autopsy indicated no overt signs of distress or damage (i.e. lethargy, fin or snout erosion, skin lesions, exophthalmos, external or internal bleeding). Gross examination of gills showed no increased mucous production nor signs of damaged tissue attributable to any strengths of paydirt (5° or 15°C tests) or overburden to which these fish were exposed for four days.

No changes in gill histology occurred due to exposure of any grayling to suspensions of paydirt up to and including 100,000 $mg \cdot L^{-1}$. The acute effect of higher sediment strengths (i.e. 250,000 $mg \cdot L^{-1}$) on gill morphology was not examined. Similarly, the appearance of the gill tissues examined for fish held in overburden suspensions of 0 (freshwater control) to 50,000 mg·L^{-1} for four days was identical.

The structure of the gill filaments and lamellae of all tissues examined was, in general, similar to that described as "normal" for other salmonid fish species (Herbert and Merkens 1961; Morgan and Tovell 1969; Noggle 1978). Gill filaments were covered by a thick stratified epithelium, whereas the secondary lamellae consisted of leaf-life structures composed of a pillar cell system delineating blood capillaries covered by a monolayer of flattened or slightly enlarged epithelial cells.

For the gill tissues examined, no hyperplasia, clubbing or fusion of lamellae was caused by any sediment exposures. Sediment particles were frequently observed between adjacent gill filaments of exposed fish. The amount of sediment observed appeared to be correlated with the concentration of suspended material to which fish were exposed. Otherwise, the histology of gills from fish held in suspensions of overburden or paydirt fines for four days could not be distinguished from that of the freshwater controls.

Water quality conditions (pH, temperature, conductance, dissolved oxygen content) to which grayling were exposed during the 4-day survival tests are presented in Appendices 2-4. In each bioassay, the temperature of each suspension varied by 1°C or less throughout the test period. The dissolved oxygen content of each suspension was unaffected by sediment type or strength, and was maintained above 80% saturation by the recirculating test apparatus. The pH values of each suspension were also unaffected by sediment strength or type. For both the paydirt and overburden materials, the higher ($\geq$1,000 mg·L^{-1}) concentrations of suspensions examined caused a slight ($\leq$20 umho·cm^{-1}) but consistent elevation in conductivity. This minor difference was evident within 30 min of startup of each test, and did not change appreciably with respect to time.

To the best of our knowledge, the lethal tolerance of Arctic grayling to suspended sediment has not been examined previously under controlled conditions. Available information concerning the lethal tolerance of other salmonid fish species to sediment is sparse and somewhat inconsistent. Smith (1978) reported that high concentrations (28,000-55,000 mg·L^{-1}) of suspensions prepared from two natural sediment sources were required to cause mortalities of chum salmon (Oncorhynchus keta) fry within four days. On the other hand, Herbert and Merkens (1961) reported that a 10- to 25-day exposure of juvenile rainbow trout to suspensions of kaolin or diatomaceous earth as low as 270 mg·L^{-1} caused significant mortalities of test fish. Noggle (1978) determined that the acute lethal tolerance (96-h LC50 values) to suspensions of natural sediments for groups of wild or hatchery-reared juvenile coho salmon, chinook salmon (O. tshawytscha) or steelhead trout (S. gairdneri) varied from 1,200 to 35,000 mg·L^{-1}. Differences noted were attributed largely to seasonal temperature variations, with a lower tolerance of fish to sediment observed during the summer months. This conclusion was supported by a report of lower lethal concentrations of natural sediments for non-salmonid fish species, with higher test temperatures (Rogers 1969).

The present findings for grayling indicate that this salmonid fish species can survive short-term exposure to very high concentrations of suspended inorganic or organic sediment under controlled laboratory conditions, despite changes in season and temperature. The minor (≤20%) mortalities noted for grayling acclimated to 5°C and held in 10,000 or 100,000 $mg \cdot L^{-1}$ strengths of coldwater (5°C) suspensions of inorganic sediment fines for four days suggest a decrease in lethal tolerance to sediment for fish acclimated to colder water; however, confirmation of this requires further studies. Since hatchery-reared rainbow trout swimup fry also survived acute exposure to very high strengths of the suspended inorganic fines to which grayling were exposed, one should not conclude that Arctic grayling are more tolerant to suspended sediment than other salmonid fish species. Perhaps differences in the nature of the suspended material examined in these versus previous (Herbert and Merkens 1961; Noggle 1978; Smith 1978) tests better explain the disparities in lethal tolerance to sediment noted. Assuming that other water quality conditions were compatible with fish survival, it is unlikely that suspended concentrations of the overburden muck or paydirt fines examined in these tests could be elevated sufficiently in natural streams to cause direct mortalities of resident populations of healthy juvenile Arctic grayling or other salmonid fish species due to short-term exposures.

A number of investigators have found histopathological changes in fish gills attributable to sediment exposure. Herbert and Merkens (1961) observed thickening and fusion of secondary gill lamellae of some rainbow trout exposed for several weeks to diatomaceous earth or china clay. Noggle (1978) reported notable gill histopathologies in certain juvenile salmonid fish held in inorganic sediment suspensions ≤13,000 $mg \cdot L^{-1}$ for up to 96 h. Other researchers have also reported thickening and fusion of gill lamellae in trout held in suspensions of diatomaceous earth for up to 96 h (Noggle 1978). Unlike these findings, no gill histopathologies attributable to short-term exposure of grayling to suspensions of inorganic or organic sediment were noted in the present laboratory tests. Similarly, Smith (1978) found no damage to gills of juvenile chum salmon (O. keta) acutely exposed to high (up to 55,000 $mg \cdot L^{-1}$) concentrations of suspended inorganic sediment.

In his review of the effects of suspended sediment on fish, Pickral (1981) cited the variability in findings of fish gill tissue damage caused by high concentrations of suspended sediment, and suggested a lack of convincing evidence for such an effect. We interpret this variability in response to differing sediment characteristics (particle shape, size, hardness), biological (fish age, size and prior history of exposure) and experimental (exposure period, test apparatus) differences. More detailed examinations of gill histology for fish held in differing types of sediment suspensions under controlled conditions are required in order to understand the relevance of these variables.

Temperature tolerance tests

Mean critical thermal maxima (upper lethal temperatures) for groups of grayling acclimated to 15°C water and tested in freshwater only were 27.5-27.9°C and variances (SD) were small (Tables 8 and 9). Mean values for fish groups held in paydirt strengths of 500-100,000 $mg \cdot L^{-1}$ were reduced slightly but consistently from control values (Table 8) and, at least for the higher sediment suspensions examined ($\geq$5,000 mg$\cdot$L^{-1}), showed a somewhat greater response to increasing sediment strengths (Fig. 10). Variances (SD, 95% confidence interval) for each group were unaffected by treatment. The highest paydirt strengths to which grayling were exposed (50,000 and 100,000 mg$\cdot$L^{-1}) reduced their mean critical thermal maxima by only 1°C.

For grayling acclimated to 15°C and held in various strengths of suspended overburden, temperatures at death were somewhat more variable and did not decline consistently from those for control fish until test concentrations exceeded a nominal strength of 1,000 mg$\cdot$L^{-1} (Table 9, Fig. 11). Mean critical thermal maxima for groups of grayling held in overburden concentrations of 5,000-50,000 mg$\cdot$L^{-1} were decreased from the control value by only 0.2-0.7°C.

Exposure of these warmwater-acclimated grayling to solutions of the reference toxicant pentachlorophenol caused a more definitive response. Sublethal strengths of pentachlorophenol (0.4 and 0.7 of the 96-h LC50 value) reduced the critical thermal maxima for grayling by 0.9 and 1.8 C respectively; a strength equivalent to 1.2 LC50 caused a further reduction (Table 10). Variances (SD values) in temperature at death were also increased by this toxicant.

Mean critical thermal maxima for the groups of grayling acclimated to 5°C water and tested in freshwater only were 24.8-24.9°C. Upper lethal temperatures for these coldwater-adapted fish were not reduced by any paydirt suspensions to which they were exposed, up to and including 50,000 mg$\cdot$L^{-1} (Table 11; Fig. 12). Standard deviations calculated for each group (including control fish) were greater than any found for groups of grayling acclimated to 15°C.

The median effective concentration (EC50) of paydirt causing a net significant decline in critical thermal maxima for grayling acclimated to 15°C was 100 mg$\cdot$L^{-1} (95% confidence interval, 50-500); whereas that derived for overburden was 8,471 mg$\cdot$L^{-1} (1,574->50,000). No value could be calculated for the coldwater-acclimated grayling exposed to paydirt suspensions, as no response to sediment was observed.

The upper lethal temperature tolerance for Arctic grayling, determined in this study for groups of fish held in clear freshwater only, was similar to values derived previously under identical procedures using underyearling coho salmon or rainbow trout (McLeay and Howard 1977; McLeay and Gordon 1980). LaPerriere and Carlson (1973) reported earlier that the (high) thermal tolerance of various life stages of Arctic grayling was similar to other salmonid fish species. The increased resistance to high temperature with an increased temperature of acclimation (15°C vs 5°C) noted for grayling in the present study is also consistent with earlier findings for other species of salmonid fish (Brett 1952; Black 1953). The seasonal photoperiod to which fish are acclimated can also influence thermal tolerance (McLeay and Gordon 1978). Thus differences noted in temperature tolerance of grayling acclimated to 15° or 5°C probably reflect the effect of a number of variables (i.e. seasonal photoperiod, developmental stage of fish, fish condition) besides the temperature to which fish were acclimated.

Sublethal concentrations of a number of aquatic contaminants (i.e. pulpmill effluent, herbicides, certain heavy metals) have been shown previously to cause a concentration-related decrease in the temperature tolerance of salmonid fish (McLeay and Gordon 1978, 1980). The degree to which this tolerance is impaired is contaminant-specific; and findings to date indicate that contaminants which block oxygen exchange at the gills, or otherwise impair tissue respiration, cause a greater effect than those which exert their toxic effects in other ways (Wedemeyer and McLeay 1981).

Since sublethal strengths of some aquatic contaminants can lower the upper lethal temperature tolerance of salmonid fish by as much as 4-5°C (McLeay and Gordon 1978, 1980), the minimal (≤1°C; 15°C fish) or negligible (5°C fish) responses caused by exposing grayling to very high concentrations of suspended inorganic or organic sediment indicate that these sediment loadings do not interfere to a large extent with the immediate thermal adaptive capacity of grayling. These findings, considered together with findings of thermal tolerance effects noted previously for salmonid fish and other aquatic contaminants, suggest that short-term exposure of juvenile grayling to high loadings of suspended sediment may not impair their tissue respiration to a significant extent. Nevertheless, the threshold-effect (EC50) levels of 100 $mg \cdot L^{-1}$ (paydirt) and 8,471 $mg \cdot L^{-1}$ (overburden) determined for the 15°C-acclimated grayling indicate that a measurable reduction in critical thermal maxima for these fish was caused by these and higher sediment strengths. The environmental relevance of this response cannot be ascertained without further studies.

The greater reduction in critical thermal maxima values for grayling exposed to pentachlorophenol in this study was consistent with that for other salmonid fish species challenged with this reference toxicant (McLeay and Gordon 1980). This finding indicates that the tolerance of grayling to temperature extremes is similarly influenced by this aquatic contaminant, and that the magnitude of effect is dependent on both the nature and concentrations of toxicant to which fish are subjected.

Sealed jar bioassays

Mean times to death for groups of warmwater-acclimated (15°C) grayling held in jars containing various strengths of paydirt sediment increased progressively with concentration (Table 12, Fig. 13). However, mean residual oxygen values for each treatment did not differ from control values (Table 12, Fig. 14). A repeat of this bioassay test using paydirt suspensions and coldwater-acclimated (5°C) fish showed no effect of this inorganic sediment on either times to death or residual oxygen values at death of these fish (Table 13, Figs. 15 and 16).

Unlike these findings, times to death for groups of grayling held in jars containing suspensions of overburden decreased progressively with increasing sediment strength (Table 14, Fig. 17). Residual oxygen values for each treatment were somewhat more variable than was found for fish held in paydirt, but showed no consistent change with respect to concentration (Table 14, Fig. 18).

Median effective concentrations (nominal) of paydirt or overburden which affected times to death of the 15oC-acclimated grayling were 4,407 mg·L-1

(297-22,933 $mg \cdot L^{-1}$) and 161 $mg \cdot L^{-1}$ (4-615 $mg \cdot L^{-1}$), respectively. Threshold-effect concentrations could not be calculated for residual oxygen levels due to the absence of consistent responses of this variable in each of the sealed jar bioassays conducted.

Mean test temperatures (20.0-20.5°C for 15°C-acclimated fish; 9.2-9.9°C for 5°C-acclimated fish) were held near-constant in each bioassay (Tables 12-14). Concentrations of paydirt remaining in suspension at the end of each 30-min settling period were decreased approximately 2- to 3-fold from respective values for the freshly-agitated suspensions (Tables 12 and 13). The overburden suspensions to which fish were exposed in sealed jar bioassays settled to an even greater extent (Table 14) prior to their re-suspension.

Grayling exposed to pentachlorophenol in sealed jar bioassays showed a concentration-dependent increase in residual oxygen values, together with a a progressive decrease in times to death of fish (Table 15). Sublethal strengths of 35 $ug \cdot L^{-1}$ (0.5 of the 96-h LC50 value) and 50 $ug \cdot L^{-1}$ (0.7 LC50) elevated residual oxygen values from those determined for each of the control (freshwater) groups.

The tolerance of the warmwater-acclimated grayling to hypoxia (oxygen deficiency) was similar to that found previously for underyearling coho salmon or rainbow trout under identical test conditions (McLeay 1976; Gordon and McLeay 1977). The critical residual dissolved oxygen level at which each of these fish species die, if acclimated to 15°C and held in freshwater at 20°C, is approximately 2.0 mg $O_2 \cdot L^{-1}$. The even greater tolerance to hypoxic conditions found in the present bioassays with grayling acclimated to 5°C and tested at 10°C (critical value approximately 1.5 mg $O_2 \cdot L^{-1}$) is also consistent with findings for other salmonid fish in response to a decrease in test temperature (Gordon and McLeay 1977). LaPerriere and Carlson (1973) cited field observations of Arctic grayling under ice cover, where the dissolved oxygen concentration of the surrounding water approached 0 $mg \cdot L^{-1}$. The present findings do not suggest a greater capacity to adapt to hypoxic conditions for this species than has been determined previously for other salmonid fish.

The respiratory responses of grayling to pentachlorophenol (elevated residual dissolved oxygen values, decreased times to death) are consistent with the response to this reference toxicant noted for underyearling rainbow trout when tested under identical conditions (McLeay and Gordon 1980). This toxicant is known to increase the oxygen consumption rate of salmonid fish, and is believed to uncouple mitochondrial respiration (Chapman and Shumway 1978).

The progressive decline in times to death of grayling exposed to increasing strengths of overburden (Fig. 17) is likely due to the high oxygen demand demonstrated for this organic sediment (Table 2), and does not reflect a respiratory response of the test fish. On the other hand, the increase in mean times to death for 15°C-acclimated grayling, with increasing strengths of paydirt (Fig. 13), does suggest a reduction in respiratory rate attributable to this inorganic sediment. This response could be due to increased swimming activity of fish in the clear solutions, in response to visual "disturbance" during the bioassay. Alternatively, it could reflect decreased physical activity, reduced ventilatory rate, or decreased efficiency of oxygen transfer, caused by progressively higher strengths of paydirt. The significance of this response is unclear in view of the lack of effect of these paydirt suspensions on the fishes' tolerance to hypoxia (Fig. 14), and on the absence of a time-to-death response to paydirt for grayling acclimated to cold water (Fig. 15).

The effect of suspended sediment on the respiration rate of fish has not been examined to any extent. Neumann et al. (1975) reported no change in the respiratory rates of oyster toadfish (Opsanus tau) held briefly in a 2,000 $mg \cdot L^{-1}$ suspension of natural sediment; although a 72-h exposure to 11,000 $mg \cdot L^{-1}$ caused a greater variance in oxygen uptake rates compared with control fish.

Aquatic contaminants known to affect fish respiration normally cause a concentration-dependent increase in residual oxygen levels of salmonid fish held in sealed jars (McLeay 1976; Vigers and Maynard 1977); whereas those contaminants known to exert their toxic effects otherwise may not effect this response (McLeay and Gordon 1980). The absence of significant changes in residual oxygen values for grayling held in suspensions of paydirt or overburden suggests either that these sediments do not impair their tolerance to hypoxic conditions, or that the strengths of sediment to which fish were exposed were too low to evoke a response. The elevated residual oxygen values for grayling held in sublethal strengths of pentachlorophenol confirm that these fish will indeed show a response in this bioassay test to a contaminant known to affect fish respiration. The absence of gill lesions associated with 4-day exposures of grayling to these sediments, together with the limited-if-any effects of paydirt or overburden suspensions on their temperature tolerance, further support the suggestion that short-term exposure of underyearling grayling to high suspended loadings of either of these sediment types does not impact their respiratory capacity.

Acute stress bioassays

Hematocrit values for groups of warmwater-acclimated grayling held in differing strengths of paydirt or overburden for 24 h were unchanged from corresponding control values (Tables 16 and 17). However, mean leucocrit values for these fish were consistently decreased by exposure to nominal sediment strengths of 1,000 $mg \cdot L^{-1}$ and higher (Figs. 19 and 20). Median effective concentrations of paydirt and overburden causing this response were 51,651 $mg \cdot L^{-1}$ (2,381->100,000 $mg \cdot L^{-1}$) and 5,843 $mg \cdot L^{-1}$ (2,092-29,107 $mg \cdot L^{-1}$), respectively. Leucocrit values for the groups of control fish sampled at the beginning and end of these bioassay tests did not differ appreciably (means, 1.2-1.4%; Tables 16 and 17).

Blood sugar values determined for these fish were also affected by sediment. Results for fish exposed to differing suspensions of paydirt were inconsistent. Generally, means and/or 95% confidence intervals for groups of fish exposed to paydirt strengths of 500 $mg \cdot L^{-1}$ or higher were increased from control values (Fig. 21); although blood sugar values for fish held in 5,000 $mg \cdot L^{-1}$ were unchanged from those for the final control group.

The elevated plasma glucose levels for the initial control group were atypical of the final controls and of other groups of control fish (Tables 16-18). These inconsistencies prevented the calculation of a threshold-effect concentration.

Plasma glucose values for groups of fish exposed to suspensions of overburden were consistently elevated from those for control fish (Table 17; Fig. 22). The median effective concentration of overburden causing this response was less than 50 $mg \cdot L^{-1}$.

As with these acute stress bioassays, hematocrit values determined for the groups of warmwater-acclimated grayling surviving a 4-day exposure to inorganic or organic suspensions were unchanged from values for controls (Tables 5 and 6). Mean hematocrit values derived for all groups of coldwater-acclimated grayling were again unaffected by sediment treatment; although these values were decreased consistently from those for the warmwater-acclimated fish (Table 7). Leucocrit values for all groups of coldwater-acclimated grayling examined (including control fish) were declined from values for warmwater-acclimated fish held in freshwater and were unchanged by treatment (Table 7).

Plasma glucose levels for all groups of coldwater-acclimated grayling surviving a 4-day exposure to paydirt differed from those for the control group. Paydirt concentrations of 500 $mg \cdot L^{-1}$ and higher caused a consistent increase in sample means and 95% confidence intervals (Table 7; Fig. 23).

Fish hematocrit values generally are highly correlated with both erythrocyte (red blood cell) counts and blood hemoglobin content (Houston and DeWilde 1968, 1972). The decrease in hematocrit noted in this study for underyearling grayling acclimated to cold water has been reported previously for other species of salmonid fish (Banks et al. 1971).

Hypoxic conditions cause significant increases in hematocrit values for salmonid fish (Holeton and Randall 1967; Swift and Lloyd 1974; Casillas and Smith 1977). However, changes in hematocrit values are somewhat resistant to acute stress, including that caused by exposure of fish to sublethal concentrations of a variety of aquatic contaminants (McLeay and Gordon 1977, 1979, 1980).

As in the present studies, Noggle (1978) reported that hematocrit values of underyearling coho salmon were unchanged by holding fish for 96 h in suspended sediment concentrations equivalent to 0.8 of the 96-h LC50 value. Other studies with non-salmonid fish species given short-term exposure to sediment have found unchanged, elevated or depressed hematocrit values (Berry 1973; Neumann et al. 1975).

Unlike hematocrit values, leucocrit values (or numbers of circulating leucocytes; i.e. white blood cells) for salmonid fish can change rapidly and dramatically in response to stress (McLeay 1975; McLeay and Gordon 1977; Wedemeyer and McLeay 1981). Short-term exposure of rainbow trout or coho salmon to sublethal concentrations of aquatic contaminants as low as 0.1 of the 96-h LC50 can cause significant declines in these values, provided that test fish are in good condition and unstressed beforehand (McLeay and Howard 1977; McLeay and Gordon 1979, 1980). The general decline in leucocrit values for warmwater-acclimated Arctic grayling held in suspensions of paydirt or overburden for 24 h indicates that each of these sediment types was stressful to these fish. Values for control groups were similar to those found previously for underyearling coho salmon, and somewhat elevated from control values for rainbow trout (McLeay and Gordon 1977). The absence of a consistent leucocrit response for the coldwater-acclimated grayling may reflect the influence of prior stress (i.e. disturbances to all control and test fish during the 4-day exposure period) or perhaps a differing mechanism of response to stress for coldwater- versus warmwater-acclimated fish.

The stress reactions (depressed leucocrit values, elevated plasma glucose values) found for grayling exposed for 24 h to sublethal strengths of pentachlorophenol (Table 18) are typical of the acute responses shown previously to be elicited for underyearling rainbow trout by this toxicant (McLeay and Gordon 1980). Diverse environmental stressors including sublethal strengths of aquatic contaminants are known to cause a rapid elevation and/or increased variance in blood sugar levels for groups of salmonid fish (McLeay 1977; Wedemeyer and McLeay 1981). A consideration of the blood sugar changes found in the present tests, together with the leucocrit changes for sediment-exposed fish, confirm that sublethal strengths of the paydirt and overburden suspensions examined were indeed acutely stressful to Arctic grayling. The variations in plasma glucose levels noted for coldwater-acclimated grayling exposed to suspensions of paydirt for 96 h indicate that grayling are stressed by this inorganic sediment, regardless of season or acclimation temperature.

Other studies of the hematological effects of sediment suspensions on fish are limited. Noggle (1978) found that blood sugar values for goups of coho salmon held for 96 h in inorganic sediment suspensions $\geq$0.2 LC50 were significantly changed from those for control fish. Similarly, O'Connor et al. (1977) reported that the laboratory exposure of a number of species of estuarine fish to suspensions of natural sediments caused hematological changes indicative of stress responses.

General

The threshold-effect concentrations (EC50) of paydirt or overburden suspensions calculated to cause acute responses for Arctic grayling in the present series of laboratory bioassays are summarized in Table 19. The EC50 values presented are based on nominal (pre-weighed) strengths of sediment to which fish were exposed. From these data it can be seen that the acute lethal tolerance of both warmwater- and coldwater-acclimated grayling to suspensions of organic and/or inorganic sediment was too high to permit the calculation of LC50 values. For fish acclimated to 15°C, threshold-effect values were derived for some of the sublethal responses monitored (i.e. critical thermal maxima; leucocrit; time to death in sealed jar bioassays); whereas values could not be determined for other tests due to the absence of effect (i.e. residual oxygen) or increased variability of response (i.e. plasma glucose values for paydirt-exposed fish) caused by treatment. No threshold-effect values could be derived for fish acclimated to 5°C and challenged with differing suspensions of paydirt due to the absence (in the temperature tolerance and sealed jar bioassays) or increeased variability of responses (in the acute stress test) caused by sediment exposure.

As with other hematological changes, variations in blood sugar values or blood cell counts (including leucocrit values) of fish in response to environmental alterations reflect a number of dynamic adaptive reactions. Such changes in regulatory precision of blood constituents may be evident by upward or downward shifts in values from the norm, although effects are also shown in many instances by increased variations in sample values from the normal range (Blaxhall 1972; Wedemeyer and Nelson 1975). The present changes noted in blood sugar and leucocrit values of grayling due to suspensions of inorganic or organic sediment are consistent with these homeostatic effects. In such instances, the calculation of EC50 values based on a net significant increase (for blood sugar) or decrease (for leucocrit) of these values is inappropriate (Table 19). Derivation of meaningful threshold-effect concentrations for these tests would require the determination of normal ranges of these blood constituents for control fish, using a large sample size ($n \geq 200$) (Wedemeyer and Nelson 1975). Individual values for each sediment-exposed fish would then be examined to determine if they were within this range.

The present laboratory bioassays with inorganic and organic sediment indicate that these sediment types can cause dissimilar sublethal effects for Arctic grayling (i.e. time to death in sealed jar bioassay), or may differ appreciably in threshold-effect concentrations (Table 19). The nature of suspended sediment (including particle constituents, size and angularity), water velocity and other environmental variables may contribute significantly to the manner and extent to which it causes adverse biological effects.

FIELD STUDIES

Water quality

A summary of the results of all water quality sampling is presented in Tables 20 and 21. Detailed water quality data are presented in Appendices 5 through 9. The data indicate that turbidity and nonfiltrable residue were elevated in Highet Creek which was being mined, relative to Minto Creek upstream of the junction, during both August and September. Total volatile residue (organic material) was a small component of total residue in both streams. Turbidity in Highet Creek in August had a mean value of 51 FTU and a range of 3 to 250 FTU, whereas in September mean turbidity was higher (636 FTU) and ranged from 100 to 2,250 FTU (Appendices 5 and 6). The mean turbidity level in Minto Creek during August was 1.1 FTU (range, 0.7 to 1.8 FTU) and, in September, was 0.9 FTU (0.5 to 1.8 FTU). Nonfiltrable residue (suspended solids) reflected the same trends as turbidity for the two streams (Table 20), indicating the substantially higher load of suspended material being transported in Highet Creek as a result of placer mining activity upstream. Inclusion of dissolved solids with suspended solids (total residue) did not appreciably alter this similarity.

Turbidity and total residue in Highet Creek during the two test periods showed similar trends and are illustrated in Figures 24 and 25. Turbidity and total residue were lower in Highet Creek in August than they were in September, reflecting differences in mining activity. The maximum total residue in August was 294 $mg \cdot L^{-1}$ but in September reached 1,900 $mg \cdot L^{-1}$. It is apparent upon examination of Figs. 24 and 25 that the suspended sediment concentration at the test site was consistently higher between 1800 h and 0800 h each day. The approximate 10-h delay between the daily onset of mining ($\sim$0800 h) and the increase in sediment concentration was due to the travel time for transport of sediment between the test site and the mining operations, together with the retention time of the settling pond.

Particle size analysis of suspended solids within Highet Creek is shown in Table 22. The distribution of particles was similar between the two test periods. These analyses showed that all solids were less than 400 um in diameter. Solids between 2 and 50 um in August comprised 83.9% of the material, and in September 88.7% of the material.

Comparison of residue and turbidity values for Highet Creek water samples from inside and outside the net enclosures showed inconsistent results. Nonfiltrable residue concentrations in the grab samples were usually highest, averaging approximately 50% greater than automatic sampler values (Appendix 9). However, total residue and turbidity levels for samples taken within or outside of the cages showed much smaller differences.

Dissolved oxygen remained near saturation in both streams during the two study periods (Table 20). Both Minto and Highet creeks exhibited circumneutral pH, with Highet Creek ranging between 6.9 and 7.9 during the two study periods and Minto Creek ranging from 6.5 to 7.5 during the same time periods. Water temperature was also monitored and showed variability between the two sites.

The temperature of Minto Creek water at the study site was relatively stable during each of the two test periods, ranging from 12° to 14°C in August and 5° to 7°C in September (Table 20). Temperature was probably maintained within these small ranges due to the stabilizing effect of Minto Lake, a few kilometres upsteam. Highet Creek exhibited the more usual temperature variation of free flowing streams which are more responsive to changing air temperatures. Water temperatures in this or other streams being mined may also be influenced through the use of the stream in removing frozen or cool temperature soils material. Temperatures in Highet Creek during August ranged from 7° to 12°C and during September, from 1° to 9°C (Table 20). The studies had been planned to coincide with warm water periods in August and cool water periods in September. This was achieved, although daily temperature regimes in the two streams were somewhat different.

Several water quality characteristics for Minto and Highet creeks were determined at the beginning and conclusion of the two test periods. In addition, a single determination of the same characteristics was made on Mud Creek water, as some fish for the second test came from this creek. Results of all samplings are shown in Table 21. These data show the normal slight increase in hardness and alkalinity with increasing contribution of groundwater flows in late summer low flow periods. Hardness and alkalinity values were highest in Mud Creek (141 and 120 $mg \cdot L^{-1}$, respectively); slightly lower in Minto Creek (110 to 123 $mg \cdot L^{-1}$ and 100 to 112 $mg \cdot L^{-1}$, respectively); and lowest in Highet Creek (73 to 80 $mg \cdot L^{-1}$ and 50 to 52 $mg \cdot L^{-1}$, respectively). As expected, calcium was the predominant anion in the three streams, ranging from 23.0 to 41.4 $mg \cdot L^{-1}$, whereas magnesium ranged from 3.3 to 9.1 $mg \cdot L^{-1}$ (Table 21).

Analysis showed that most metals were either not different in concentration between streams, or were below the analytical detection limits (Table 21). Particular metals of concern which were below detection limits at all times were lead, copper, mercury, and cadmium. Iron was found to be lower than detection limit in Mud Creek, and ranged from 0.1 to 0.5 $mg \cdot L^{-1}$ in Minto and Highet creeks. Strontium was found to be higher in Minto and Mud creeks (0.20 to 0.23 $mg \cdot L^{-1}$) than in Highet Creek (0.12 to 0.14 $mg \cdot L^{-1}$). Tin was above detection limit only during September in Highet Creek, when levels of 0.11 to 0.17 $mg \cdot L^{-1}$ were reached. No guidelines have been established for the protection of aquatic biota for either strontium or tin (McNeely et al. 1979).

Four other metals (arsenic, manganese, zinc, and aluminum) were found to exceed recommended levels or tentative limits for the protection of aquatic biota on at least one occasion within the study area. Arsenic was above detection limits in Highet and Minto creeks only during August (Table 21). Levels in Minto Creek ranged from 0.01 to 0.07 $mg \cdot L^{-1}$, whereas in Highet Creek levels reached 0.1 to 0.2 $mg \cdot L^{-1}$. Arsenic levels defined as hazardous in the aquatic environment are 0.05 $mg \cdot L^{-1}$, or 0.01 $mg \cdot L^{-1}$ as presenting minimal risk to aquatic organisms (McNeely et al. 1979). Manganese was not detectable in Mud Creek or Minto Creek in September. However, manganese was found to be 0.014-0.016 $mg \cdot L^{-1}$ in Minto Creek during August, and, in Highet Creek, 0.013 to 0.027 $mg \cdot L^{-1}$ in September and 0.048 to 0.052 $mg \cdot L^{-1}$ in August. Higher levels of manganese were found in August in the two study streams and in Highet Creek exceeded the recommended level of 0.02 $mg \cdot L^{-1}$ (McNeely et al. 1979) in both periods (but only marginally in September). Zinc was detectable at all sites on all occasions (Table 21). Minto Creek zinc concentrations ranged from 0.02 to 0.03 $mg \cdot L^{-1}$, and Highet Creek concentations ranged from 0.02 to 0.05 $mg \cdot L^{-1}$. The recommended level of zinc for the protection of aquatic organisms is 0.03 $mg \cdot L^{-1}$ (McNeely et al. 1979), which is met or exceeded marginally in both study streams. Aluminum concentrations were found to be highest in August in both study streams and higher in Highet Creek than Minto Creek. Minto Creek levels ranged from <0.05 to 0.05 $mg \cdot L^{-1}$, whereas concentrations in Highet Creek ranged from 0.1 to 0.3 $mg \cdot L^{-1}$. No recommended limits for aquatic organism protection have been established for aluminum, although a tentative limit of 0.1 $mg \cdot L^{-1}$ has been identified (McNeely et al. 1979).

As indicated, four metals were found to exceed recommended or tentative limits for total metals derived for the aquatic environment. The metal values indicated in the present report are total levels; that is, all forms of the metal, whether combined with other elements, adsorbed to particles, or ionic. It is known that most metals are not acutely toxic to aquatic organisms in the non-ionic state, and that toxicity is not directly related to total metal values. In addition, at the pH and relatively high calcium levels found in the study area, it is expected that a large portion of the total metals measured would be in a non-ionic state.

Caged fish studies

Fish survival

During the August tests, all grayling held for four days in cages within Highet Creek or Minto Creek were alive (Table 23) and in apparently good condition at the end of this exposure period. No signs of fish distress or injury were evident at either site. Similarly, all grayling captured from Minto Creek and held at the Highet and Minto Creek sites for five days during September 1982, survived. However, 16% (five fish) of the Mud Creek fish held in Highet Creek during September died within 96 h (Table 23). All Mud Creek fish held in cages within Minto Creek survived the 120-h (5-day) test period.

Although Mud Creek fish held in Minto Creek survived the test period while 5 of the 32 Mud Creek fish in Highet Creek died, it cannot be stated with certainty that suspended sediment (nonfiltrable residue) was the sole factor contributing to these fish deaths. Additionally, since all but one of these five fish survived the initial 48-h period following their transfer from Mud Creek (Table 23), the fish deaths were not caused by transfer shock alone. Perhaps these fish were unable to withstand the stress loading imposed upon them by the combined effects of capture, transport, confinement and the more rigorous environmental conditions within Highet Creek (daily fluctuations of water temperature to near zero, together with suspended sediment concentrations $\leq$1,210 $mg \cdot L^{-1}$).

Our findings that wild Arctic grayling in stream environments can survive short-term exposure to suspended sediment concentrations of up to 1,210 $mg \cdot L^{-1}$ are in general agreement with other field observations for this salmonid fish species. In a similar study, Simmons and LaPerriere (1982) found that underyearling Arctic grayling held for 7-10 days in the highly turbid ($\geq$1,000 NTU) water of Birch Creek, downstream of placer mining activities, survived. Atkins-Baker (MS, 1980) also reported 100% survival of fingerling grayling held for 4 days in Hunker Creek when suspended sediment strengths ranged from 335 to 22,000 $mg \cdot L^{-1}$; although mortalities of caged fish were noted for other creeks in association with peak loadings of suspended sediment. Mathers et al. (1981) captured adult grayling during July from other Yukon creeks (Clear, Duncan, Johnson) receiving placer mining effluent, at times when suspended sediment concentrations varied from 114 to 4,453 $mg \cdot L^{-1}$, whereas fry were not found. These investigators did note, however, "On the other hand, good catches of grayling, both adults and fry, were obtained in Sulphur Creek. In this area suspended sediment concentrations were about 100 $mg \cdot L^{-1}$".

Gill histology

All gills of fish caged in Highet or Minto Creek during August or September appeared "normal" when inspected upon termination of these field bioassays. No loss of red coloration was evident, and clogging of filaments with sediment particles was not observed. Additionally, no signs of increased mucous production were seen on either occasion for gills of fish caged in Highet Creek. Subsequent microscopic examination of gill arches preserved with polyvinyl lactophenol also revealed no damage to gill filaments of fish held at either site on these occasions.

The detailed examination of gill tissues from grayling held in cages within Minto or Highet Creek during September 1982 showed histopathological changes at each site. Whereas the structure of gill filaments and secondary lamellae for uncaged fish captured directly from Minto Creek at this time was normal in appearance (Fig. 26), that of fish held captive in both Minto Creek and Highet Creek was not (Fig. 27). Moderate-to-marked hypertrophy (increase in cell size) and hyperplasia (increase in cell number) of the lamellar epithelium was evident for gills of all caged fish examined (Table 24). Additionally, the frequency of gill ectoparasites (tentatively identified as monogenetic trematodes) noted occasionally for three of the five uncaged upstream Minto Creek fish examined was increased appreciably for fish caged at each site (Figs. 26 and 27; Table 24). With the exception of the infrequent observations of particulate debris (sediment) between gill filaments of fish caged in Highet Creek, no differences in gill histomorphologies for fish caged in Highet Creek versus Minto Creek were evident.

Wobeser et al. (1976) reported severe lamellar hyperplasia for gill tissues of captive Arctic grayling infested with large numbers of monogenetic trematodes. Birtwell et al. (1983) also found extensive gill histopathologies for adult Arctic grayling captured from Minto Creek downstream of its junction with Highet Creek. The present association of gill lesions with increased numbers of ectoparasites for caged grayling suggests that the histopathologies noted were caused by these parasites. Other investigators (Williams 1967; Kearns 1968) have reported a rapid buildup of gill parasites for wild fish held in captivity, as was found in this instance.

The absence of any increased gill mucous production or of histopathological changes attributable to the suspended sediment loadings to which grayling were exposed in Highet Creek is consistent with our laboratory findings. Unlike these results, Simmons and LaPerriere (1982) observed increased gill mucous secretions for wild underyearling Arctic grayling held for 7-10 days in turbid water downstream of placer mining activity. In a separate field study, Herbert et al. (1961) reported gill lesions for trout captured from sediment-laden streams, whereas those taken from clearwater streams were normal. However, these differences may have resulted from prolonged exposure of fish to sediment. The conflicting reports from field or laboratory studies of the presence or absence of gill histopathologies attributable to exposure of fish to suspended sediment suggest that factors such as particle type (shape, size), sediment concentrations, and duration of fish exposure likely determine whether or not direct damage to gill tissue will occur.

Hematology

The hematocrit values determined for groups of fish held in Minto Creek or Highet Creek during August and September were similar, and apparently unaffected by the differing water quality conditions noted for each site. On the other hand, plasma glucose values determined for the grayling sampled from Minto Creek cages or directly from Mud Creek during August 1982 were similarly and consistently low; whereas mean glucose values for fish sampled from the Highet Creek cages at this time were elevated by approximately 30% (Table 25). Mean blood sugar values for grayling held in Highet Creek during September were increased from those for fish caged in Minto Creek by greater than 100%, regardless of fish source. These findings suggest that the water quality conditions to which grayling were exposed in Highet Creek, on each of the two occasions that the field bioassays were conducted, were more stressful to these fish than those within Minto Creek.

Our findings from controlled laboratory bioassays with inorganic or organic sediments indicate that suspended sediment strengths within the range of those found in Highet Creek during August or September can cause changes in blood sugar and leucocrit values, which typify short-term reactions to stressors. The relatively colder and more variable water temperatures for Highet Creek during August and September (Table 20) may also account for the site-specific differences in plasma glucose values noted on each occasion. During the extended period required for salmonid and other fish species to acclimate to cold water, a number of physiological stress responses normally occur, including the elevation of blood sugar levels (Schuh and Nace 1961; Nace and Schuh 1961; Allan 1971). The capture, transport, and confinement of fish can also cause appreciable changes in their blood sugar regulation (Silbergeld 1974; Hattingh 1976; McLeay 1977). Thus the elevated blood sugar values noted for grayling caged in Highet Creek likely reflect the combined influence of suspended sediment together with other stressors such as fluctuating water temperatures.

CONCLUSIONS

The present laboratory bioassays demonstrate that underyearling Arctic grayling can survive short-term exposure to very high levels ($\geq$50,000 mg·L^{-1}) of suspended inorganic or organic sediment. Season (including acclimation temperature) does not cause any marked changes in this tolerance, although test results suggest a slight reduction in lethal tolerance to suspensions of inorganic paydirt for grayling acclimated to cold (5°C) water. These laboratory findings are consistent with the fish-survival data obtained for grayling held in turbid waters downstream of placer mining activity for 4 or 5 days.

No gill histopathologies were found in either laboratory or field tests which could be attributed to acute exposure of grayling to sediment. Additionally, the laboratory bioassays indicated that the tolerance of grayling to hypoxic conditions or to upper lethal temperatures was not appreciably affected by suspensions of inorganic or organic sediment. The environmental significance of the slight but consistent decrease in critical thermal maxima for warmwater-acclimated grayling exposed to paydirt suspensions $\geq$100 mg·L^{-1} or to suspensions of overburden $\geq 8,000$ mg·L^{-1} (based on EC50 values) is not known at the present time. Nor is the significance of the increased time to death (reduced oxygen uptake rate) for warmwater-acclimated grayling only, caused by paydirt suspensions $\geq 4,000$ mg·L^{-1}, understood. The finding of decreased times to death for grayling held in sealed jars containing overburden concentrations ≥ 160 mg·L^{-1} is thought to reflect the oxygen demand of this organic muck. The environmental relevance of this oxygen demand is site-specific, and would be modified markedly by factors such as overburden type and loading to receiving waters, flow conditions, water temperature and presence or absence of ice cover.

The acute stress bioassays demonstrate that suspensions of both paydirt and overburden can be acutely stressful to underyearling Arctic grayling. Further, the test results indicate that suspended sediment strengths as low as 50 mg·L^{-1} (overburden) may be stressful to these fish; and that stress responses can be evoked for both coldwater- and warmwater-acclimated fish. Differences in blood sugar values noted on each of two occasions for grayling caged in Highet versus Minto Creek also suggest that the Highet Creek site was more stressful to these fish. The environmental relevance of these responses to the immediate survival and long-term wellbeing of Arctic grayling cannot be ascertained without further studies. However, stressful conditions are well known to reduce the adaptive responses of other salmonid fish species to natural environmental fluctuations, and to increase the susceptibility of fish to disease (Wedemeyer et al. 1976; Wedemeyer and McLeay 1981).

Results from the present laboratory and field studies should provide some direction for future investigations concerned with the acute or long-term biological effects of suspended sediment on resident fish species, and with appropriate water quality objectives for sediment. The influence of sediment concentration and type (including particle shape and size) which causes stress responses in fish (and the environmental significance of these responses) deserves further attention, as does the impact of more prolonged exposures. Effects of sediment type and strength on fish behavioural responses (i.e. feeding, avoidance/preference reactions) and on other life stages are also largely unknown at present. A basic understanding of the degree to which these responses may be altered by sediment is essential before the biological relevance to Arctic grayling or other sensitive aquatic species of specific sediment loadings within natural waterbodies can be fully appreciated.

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TABLE 1. Particle size distribution for paydirt and overburden sediment samples.

Sieve size (mesh)	Particle size (μm)	Paydirt (test no. 1)		Paydirt (test no. 2)		Overburden	
		weight (%)	cumulative weight (%)	weight (%)	cumulative weight (%)	weight (%)	cumulative weight (%)
+35	>400	0.0	0.0	0.0	0.0	31.0	31.0
+48	>300	0.0	0.0	0.1	0.1	9.5	40.5
+65	>210	0.2	0.2	0.7	0.8	8.9	49.4
+100	>150	1.5	1.7	3.8	4.6	11.2	60.6
+150	>100	6.9	8.6	8.9	13.5	9.2	69.8
+200	>75	9.4	18.0	9.2	22.7	7.3	77.1
+325	>45	9.8	27.8	9.4	32.1	8.6	85.7
+400	>38	6.8	34.6	7.5	39.6	11.0	96.7
-400	<38	65.4	100.0	60.4	100.0	3.3	100.0

TABLE 2. Moisture content, volatile and fixed residue, and oxygen uptake rate for paydirt and overburden sediment samples.

Characteristic	Test No.	Sediment type	
		paydirt	overburden
	1	2.3	81.8
moisture content (%)	2	2.8	84.6
	3	2.5	82.5
volatile residue (%)	1	3.6	96.0
fixed residue (%)	1	96.4	4.0
oxygen uptake rate at 15°C (mg $O_2 \cdot ml^{-1}$ sediment$\cdot$24 h^{-1})	1	0.01	0.08
	2	0.01	0.08
oxygen uptake rate at 15°C (mg $O_2 \cdot g^{-1}$ sediment[a]$\cdot$24 h^{-1})	1	0.01	0.6
	2	0.01	0.6

[a] Based on dry weight.

TABLE 3. Metal content[a] of paydirt and overburden sediment samples.

Major components		Concentration (% dry weight)	
		paydirt	overburden
alumina	Al_2O_3	12.8	1.12
iron	Fe_2O_3	11.0	0.91
calcium	CaO	0.32	5.18
magnesium	MgO	0.91	0.36
sodium	Na_2O	0.59	0.11
potassium	K_2O	2.45	0.10
Trace components		**Concentration ($\mu g \cdot g^{-1}$ dry weight)**	
		paydirt	overburden
antimony	Sb	73.8	<15.
arsenic	As	1,570.	<30.
barium	Ba	732.	743.
beryllium	Be	<0.3	<0.3
bismuth	Bi	<50.	<50.
cadmium	Cd	<1.	<1.
chromium	Cr	136.	4.3
cobalt	Co	<5.	<5.
copper	Cu	56.1	43.3
lead	Pb	<10.	<10.
manganese	Mn	545.	2,920.
molybdenum	Mo	<4.	<4.
nickel	Ni	39.7	32.1
phosphorus	PO_4	1,740.	3,970.
silver	Ag	<0.5	<0.5
strontium	Sr	83.5	156.
tin	Sn	<3.	<3.
titanium	Ti	3,090.	229.
vanadium	V	70.4	8.9
zinc	Zn	94.6	92.0

[a] Based on analysis of sediment digest by inductively coupled argon plasma spectrograph.

TABLE 4. Effect of location within recycle test tanks on concentration (total residue values)[a] of recirculating paydirt sediment.

Nominal paydirt strength (mg·L^{-1})	Total residue (mg·L^{-1})			
	tank inflow	surface (mid-tank)	mid-depth (mid-tank)	bottom (corner)
500	857	412	380	222
5,000	7,440	3,360	3,367	4,006
10,000	21,488	8,249	8,605	10,436
20,000	37,624	13,968	15,386	18,726
100,000	351,536	62,391	71,536	85,259

[a] Aliquots (100 ml) taken for total residue analyses at 48 h after test sediment introduced to tanks.

TABLE 5. Acute survival test: Effect of a 4-day exposure to suspended inorganic paydirt fines on fish survival and on blood sugar and hematocrit values for underyearling Arctic grayling[a] acclimated to 15°C.

Paydirt concentration (mg·L^{-1})		Fish survival (%)				Plasma glucose (mg %)		Hematocrit (%)	
nominal[b]	final suspended residue[c]	24h	48h	72h	96h	Mean	SD	Mean	SD
0	0	100	100	100	100	129.8	59.1	30.6	1.9
50	76	100	100	100	100	104.2	25.5	31.6	2.8
100	261	100	100	100	100	132.2	31.3	31.0	1.6
1,000	1,090	100	100	100	100	97.6	20.8	30.4	2.1
5,000	5,401	100	100	100	100	65.6	5.1	33.2	2.3
10,000	17,390	100	100	100	100	61.0	6.2	30.2	1.9
50,000	87,768	100	100	100	100	–[d]	–	–	–
100,000	237,959	100	100	100	100	56.6	7.5	32.6	4.7
250,000	–	100	100	100	100	–	–	–	–

[a] Mean (±SD) weight, 2.9 ± 0.7 g; length, 7.1 ± 0.6 cm; condition factor, 0.79 ± 0.05.
[b] Based on weight of paydirt added to a 50-L test volume.
[c] Based on total residue for a 100-ml grab sample taken from the pump outlet at end of test.
[d] Not determined.

TABLE 6. Acute survival test: Effect of a 4-day exposure to suspended organic overburden on fish survival and on blood sugar and hematocrit values for underyearling Arctic grayling[a] acclimated to 15°C.

Overburden concentration ($mg \cdot L^{-1}$)		Fish survival (%)				Plasma glucose (mg %)		Hematocrit (%)	
nominal[b]	final suspended residue[c]	24h	48h	72h	96h	Mean	SD	Mean	SD
0	3	100	100	100	100	127.8	102.4	32.3	1.9
50	29	100	100	100	100	90.8	7.7	32.0	2.2
100	104	100	100	100	100	88.4	10.4	30.6	1.8
1,000	889	100	100	100	100	102.4	38.2	32.1	2.0
5,000	2,172	100	100	100	100	87.8	6.8	31.9	1.8
10,000	4,165	100	100	100	100	94.3	39.7	32.5	2.1
50,000	10,320	100	100	100	100	102.6	22.7	32.8	1.3

[a] Mean (±SD) weight, 3.6 ± 1.0 g; length, 7.8 ± 0.7 cm; condition factor, 0.75 ± 0.04.

[b] Based on dry weight of overburden added to a 50-L test volume.

[c] Based on total residue for a 100-ml grab sample taken from centre of tank at end of test.

TABLE 7. Acute survival test: Effect of a 4-day exposure to suspended inorganic paydirt fines on fish survival and on blood sugar, leucocrit and hematocrit values for underyearling Arctic grayling[a] acclimated to 5°C.

Paydirt concentration (mg·L^{-1})		Fish survival (%)				Plasma glucose (mg %)		Hematocrit (%)		Leucocrit (%)	
nominal[b]	final suspended residue[c]	24h	48h	72h	96h	Mean	SD	Mean	SD	Mean	SD
0	7	100	100	100	100	57.3	15.9	28.8	3.5	1.12	0.38
500	110	100	100	100	100	118.7	49.5	28.4	3.4	0.96	0.42
5,000	2,455	100	100	100	100	71.4	16.6	29.3	3.0	1.18	0.40
10,000	8,602	100	100	100	100	68.5	50.0	28.0	4.4	0.80	0.32
20,000	15,847	100	100	90	90	99.1	62.8	28.4	7.6	1.10	0.27
100,000	70,569	100	100	80	80	123.4	115.8	30.6	4.8	0.98	0.40

[a] Mean (±SD) weight, 4.5 ± 1.3 g; length, 8.4 ± 0.8 cm; condition factor, 0.76 ± 0.09.

[b] Based on weight of paydirt added to a 50-L test volume.

[c] Based on total residue for a 100-ml grab sample taken from centre of tank at end of test.

TABLE 8. Temperature tolerance test: Effect of suspended inorganic paydirt on the critical thermal maxima for underyearling Arctic grayling[a] acclimated to 15 °C.

Paydirt concentration ($mg \cdot L^{-1}$)		Temperature (°C) at death	
nominal[b]	final suspended residue[c]	Mean	SD
0 (test 1)	0	27.9	0.1
0 (test 2)	0	27.7	0.1
25	28	27.3	0.1
50	76	27.8	0.2
100 (test 1)	129	27.4	0.1
100 (test 2)	85	27.8	0.3
500	490	27.2	0.1
1,000 (test 1)	640	27.3	0.1
1,000 (test 2)	780	27.2	0.3
5,000	3,410	27.0	0.1
10,000	6,200	27.0	0.1
20,000	11,000	27.1	0.1
50,000	61,272	26.6	0.2
100,000	82,275	26.7	0.2

[a] Mean (±SD) weight, 5.1 ± 0.9 g; length, 8.3 ± 0.4 cm; condition factor, 0.90 ± 0.06.

[b] Based on weight of paydirt added to test volume.

[c] Based on total residue for 100-ml grab sample taken from centre of vessel at end of test.

TABLE 9. Temperature tolerance test: Effect of suspended organic overburden on the critical thermal maxima for underyearling Arctic grayling[a] acclimated to 15°C.

Overburden concentration ($mg \cdot L^{-1}$)		Temperature (°C) at death	
nominal[b]	final suspended residue[c]	Mean	SD
0 (control)	0	27.5	0.3
100	125	28.0	0.1
150	147	27.7	0.2
500	609	27.5	0.3
1,000	700	27.6	0.2
5,000	2,336	26.8	0.5
10,000	3,646	27.3	0.4
20,000	7,242	26.9	0.3
50,000	14,197	27.1	0.4

---

[a] Mean (±SD) weight, 4.8 ± 1.0 g; length, 8.1 ± 0.7 cm; condition factor, 0.91 ± 0.07.

[b] Based on dry weight of overburden added to test volume.

[c] Based on total residue for 100-ml grab sample taken from centre of vessel at end of test.

TABLE 10. Temperature tolerance test: Effect of pentachlorophenol on the critical thermal maxima for underyearling Arctic grayling[a] acclimated to 15°C.

Pentachlorophenol concentration ($\mu g \cdot L^{-1}$)	Temperature (°C) at death	
	Mean	SD
0 (control)	27.7	0.1
25	26.8	0.3
50	25.9	0.5
80	<25.5	-

[a] Mean (±SD) weight, 4.9 ± 0.9 g; length, 8.2 ± 0.5 cm; condition factor, 0.89 ± 0.06.

TABLE 11. Temperature tolerance test: Effect of suspended inorganic paydirt on the critical thermal maxima for underyearling Arctic grayling[a] acclimated to 5 °C.

Paydirt concentration (mg·L^{-1})		Temperature (θ °C) at death	
nominal[b]	final suspended residue[c]	Mean	SD
0 (control 1)	3	24.8	1.5
0 (control 2)	5	24.9	1.4
100	40	24.9	1.5
500	260	25.2	2.1
1,000	520	25.2	0.8
10,000	5,692	24.7	1.1
50,000	71,143	25.3	1.3

---

[a] Mean (±SD) weight, 5.5 ± 2.3 g; length, 8.5 ± 1.8 cm; condition factor, 0.81 ± 0.12.

[b] Based on weight of paydirt added to test volume.

[c] Based on total residue for 100-ml grab sample taken from centre of vessel at end of test.

TABLE 12. Sealed jar bioassay: Effect of suspended inorganic paydirt on tolerance to hypoxia and time to hypoxic death for underyearling Arctic grayling[a] acclimated to 15°C.

Paydirt concentration ($mg \cdot L^{-1}$)			Temperature at death (°C)		Time to death (min)		Residual oxygen at death ($mg\ O_2 \cdot L^{-1}$)	
nominal[b]	initial suspended residue[c]	final suspended residue[d]	Mean	SD	Mean	SD	Mean	SD
0	<1	2	20.5	0.2	228	61	2.0	0.4
0	<1	1	20.5	0.1	224	58	1.9	0.2
100	107	52	20.5	0.1	220	58	1.9	0.2
500	385	180	20.5	0.1	270	60	1.9	0.3
2,500	1,836	420	20.5	0.1	245	73	1.9	0.3
10,000	8,127	2,670	20.3	0.1	271	71	1.9	0.3
20,000	15,483	5,997	20.4	0.1	299	34	1.8	0.3
50,000	46,590	16,481	20.3	0.1	319	45	1.8	0.3
100,000	90,027	31,029	20.4	0.2	312	16	1.9	0.3

[a] Mean (±SD) weight, 10.4 ± 1.3 g; length, 10.2 ± 0.4 cm; condition factor, 0.98 ± 0.07.
[b] Based on weight of paydirt added to each of ten replicate 1.9-L glass jars.
[c] Based on total residue for a 100-ml grab sample taken immediately after the jar was inverted.
[d] Based on total residue for a 100-ml grab sample taken 30 min after the jar was inverted.

TABLE 13. Sealed jar bioassay: Effect of suspended inorganic paydirt on tolerance to hypoxia and time to hypoxic death for underyearling Arctic grayling[a] acclimated to 5°C.

Paydirt concentration ($mg \cdot L^{-1}$)			Temperature at death (°C)		Time to death (min)		Residual oxygen at death ($mg\ O_2 \cdot L^{-1}$)	
nominal[b]	initial suspended residue[c]	final suspended residue[d]	Mean	SD	Mean	SD	Mean	SD
0	6	6	9.4	0.6	491	63	1.5	0.4
0	4	5	9.7	1.0	498	94	1.6	0.4
100	66	24	9.2	1.5	452	96	1.6	0.2
500	194	81	9.6	0.6	456	87	1.7	0.5
2,500	1,699	402	9.8	0.4	438	95	1.4	0.3
10,000	7,358	1,956	9.8	0.7	487	74	1.3	0.2
20,000	11,220	5,183	9.9	0.4	478	75	1.3	0.2
50,000	42,547	14,128	9.7	0.7	440	92	1.2	0.4
100,000	68,322	28,924	9.8	0.6	518	82	1.4	0.3

[a] Mean (±SD) weight, 11.2 ± 1.1 g; length, 10.8 ± 0.5 cm; condition factor, 0.88 ± 0.06.

[b] Based on weight of paydirt added to each of ten replicate 1.9-L glass jars.

[c] Based on total residue for a 100-ml grab sample taken immediately after the jar was inverted.

[d] Based on total residue for a 100-ml grab sample taken 30 min after the jar was inverted.

TABLE 14. Sealed jar bioassay: Effect of suspended organic overburden on tolerance to hypoxia and time to hypoxic death for underyearling Arctic grayling[a] acclimated to 15°C.

Overburden concentration (mg·L^{-1})			Temperature at death (°C)		Time to death (min)		Residual oxygen at death (mg O_2·L^{-1})	
nominal[b]	initial suspended residue[c]	final suspended residue[d]	Mean	SD	Mean	SD	Mean	SD
0	<1	1	20.2	0.1	239	11	2.0	0.2
0	<1	2	20.3	0.1	227	40	2.0	0.3
100	120	43	20.3	0.1	209	44	2.1	0.3
1,000	786	347	20.3	0.1	189	22	2.3	0.4
5,000	4,123	832	20.3	0.1	203	16	1.8	0.3
10,000	7,870	941	20.4	0.1	187	35	2.1	0.6
20,000	12,870	1,027	20.3	0.1	175	36	2.1	0.4
50,000	23,200	2,723	20.0	0.1	136	24	2.3	0.6

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[a] Mean (±SD) weight, 10.3 ± 1.1 g; length, 9.9 ± 0.5 cm condition factor, 0.96 ± 0.07.

[b] Based on dry weight of overburden added to each of ten replicate 1.9-L glass jars.

[c] Based on total residue for a 100-ml grab sample taken immediately after the jar was inverted.

[d] Based on total residue for a 100-ml grab sample taken 30 min after the jar was inverted.

TABLE 15. Sealed jar bioassay: Effect of pentachlorophenol on tolerance to hypoxia and time to hypoxic death for underyearling Arctic grayling[a] acclimated to 15°C.

Pentachlorophenol concentration ($\mu g \cdot L^{-1}$)	Temperature at death (°C)		Time to death (min)		Residual oxygen at death (mg $O_2 \cdot L^{-1}$)	
	Mean	SD	Mean	SD	Mean	SD
0	20.5	0.1	228	67	2.0	0.4
0	20.3	0.1	227	49	2.0	0.3
35	20.6	0.1	195	85	2.9	0.7
50	20.3	0.1	192	57	3.2	1.3
80	20.4	0.04	163	21	3.3	0.3

[a] Mean (±SD) weight, 10.3 ± 1.1 g; length, 10.1 ± 0.4 cm; condition factor, 0.98 ± 0.07.

TABLE 16. Acute stress bioassay: Effect of suspended inorganic paydirt on blood sugar, hematocrit and leucocrit values for underyearling Arctic grayling[a] acclimated to 15°C.

Paydirt concentration (mg·L^{-1})			Plasma glucose (mg %)		Hematocrit (%)		Leucocrit (%)	
nominal[b]	initial suspended residue[c]	final suspended residue[d]	Mean	SD	Mean	SD	Mean	SD
0 (initial control)	5	8	105.8	23.7	32.4	1.4	1.18	0.22
0 (final control)	2	5	82.5	7.7	33.9	2.4	1.29	0.16
50	43	44	91.3	20.7	35.1	2.6	1.35	0.24
100	102	85	98.8	12.3	34.4	3.1	1.22	0.27
500	281	402	90.8	28.4	33.7	1.8	1.21	0.29
1,000	420	560	120.9	11.0	34.3	2.9	1.13	0.26
5,000	4,121	7,650	82.3	10.1	34.8	3.4	0.96	0.16
10,000	15,725	10,230	116.2	54.6	33.4	2.5	1.07	0.37
20,000	17,135	22,840	73.1	26.1	34.4	4.9	0.93	0.28
100,000	56,960	118,305	102.6	32.2	34.7	4.6	1.09	0.47

[a] Mean (±SD) weight, 3.8 ± 0.7 g; length, 7.9 ± 0.6 cm; condition factor, 0.76 ± 0.05.

[b] Based on weight of paydirt added to a 50-L test volume.

[c] Based on total residue for a 100-L grab sample taken from centre of vessel at 0.5 h after sediment is added.

[d] Based on total residue for a 100-ml grab sample taken from centre of vessel at end of test.

TABLE 17. Acute stress bioassay: Effect of suspended organic overburden on blood sugar, hematocrit and leucocrit values for underyearling Arctic grayling[a] acclimated to 15°C.

Overburden concentration ($mg \cdot L^{-1}$)		Plasma glucose (mg %)		Hematocrit (%)		Leucocrit (%)	
nominal[b]	final suspended residue[c]	Mean	SD	Mean	SD	Mean	SD
0 (initial control)	3	67.4	5.7	31.0	1.6	1.25	0.34
0 (final control)	5	74.4	10.2	32.0	2.2	1.36	0.46
50	30	94.5	12.8	33.1	0.6	1.22	0.39
100	190	85.8	13.5	31.6	2.0	1.35	0.13
1,000	1,590	101.2	10.1	33.2	2.0	1.15	0.13
5,000	2,757	80.9	10.4	32.8	2.1	1.15	0.14
10,000	4,696	103.3	28.0	31.4	2.5	0.95	0.29
20,000	12,296	88.2	21.9	31.3	1.6	0.94	0.33

[a] Mean (±SD) weight, 3.2 ± 0.8 g; length, 7.5 ± 0.6 cm; condition factor, 0.78 ± 0.06.

[b] Based on dry weight of overburden added to test volume.

[c] Based on total residue for a 100-ml grab sample taken from centre of vessel at end of test.

TABLE 18. Acute stress bioassay: Effect of pentachlorophenol on blood sugar, hematocrit and leucocrit values for underyearling Arctic grayling[a] acclimated to 15°C.

Pentachlorophenol concentration ($\mu g \cdot L^{-1}$)	Plasma glucose (mg %)		Hematocrit (%)		Leucocrit (%)	
	Mean	SD	Mean	SD	Mean	SD
0 (control)	70.4	13.1	32.2	2.4	1.28	0.34
20	82.9	15.7	32.3	2.6	1.22	0.27
35	129.8	25.8	32.4	2.5	0.66	0.28
50	151.3	52.1	31.4	1.5	0.74	0.41

[a] Mean (±SD) weight, 3.3 ± 0.6 g; length, 7.6 ± 0.7 cm; condition factor, 0.75 ± 0.06.

TABLE 19. Summary of threshold-effect concentrations of paydirt or overburden suspensions causing acute responses for Arctic grayling.

Bioassay test	Acclimation temperature (°C)	Exposure (h)	Response	EC50[a] (mg·L^{-1})	
				paydirt	overburden
LC50[b]	15	96	decreased fish survival	>100,000	>50,000
temperature tolerance	15	12	decreased critical thermal maxima	100 (50-500)	8,471 (1,574->50,000)
sealed jar bioassay	15	5	increased (paydirt) or decreased (overburden) time to death	4,407 (297-22,933)	161 (4-615)
sealed jar bioassay	15	5	increased residual oxygen at death	>100,000	>50,000
leucocrit stress test	15	24	decreased leucocrit values	51,651 (2,381->100,000)	5,843 (2,092-29,107)
blood sugar stress test	15	24	increased plasma glucose values	-[c]	<50
LC50	5	96	decreased fish survival	>100,000	-[e]
temperature tolerance	5	20	decreased critical thermal maxima	>50,000	-[e]
sealed jar bioassay	5	8	increased time to death	>100,000	-[e]
sealed jar bioassay	5	8	increased residual oxygen at death	>100,000	-[e]
leucocrit stress test[d]	5	96	decreased leucocrit values	-[c]	-[e]
blood sugar stress test[d]	5	96	increased plasma glucose values	-[c]	-[e]

[a] Median effective concentration causing a net significant response for 50% of fish (95% confidence interval in parentheses).

[b] Median lethal concentration.

[c] Unable to calculate due to increased variance of data.

[d] Not conducted as a stress bioassay (values based on those for fish surviving a 96-h exposure).

[e] Not measured.

Table 20. Water quality characteristics monitored at test site in Highet Creek and the control site in Minto Creek during the fish enclosure tests, August and Septemeber, 1982.

Variable	Statistic	Highet Creek		Minto Creek	
		August 1982	September 1982	August 1982	September 1982
water temperature (℃)[1]	mean	9.0	4.8	12.8	6.3
	SD[2]	1.8 (9)	2.7 (7)	0.7(7)	1.3 (7)
	range	7.0 - 12.0	1.0 - 9.0	12.0 - 14.0	5.0 - 7.0
dissolved oxygen ($mg \cdot L^{-1}$)	mean	11.0	12.6	10.2	10.2
	SD	0.7 (9)	0.9 (7)	0.7(7)	0.5 (7)
	range	9.7 - 11.5	9.5 - 13.5	9.4 - 11.0	10.0 - 10.7
pH	mean	7.4	7.2	7.3	6.7
	SD	0.3 (9)	0.2 (7)	0.2(7)	0.2 (7)
	range	7.1 - 7.9	6.9 - 7.4	7.2 - 7.5	6.5 - 6.9
turbidity (FTU)	mean	51	636	1.1	0.9
	SD	52 (60)	483 (60)	0.3(48)	0.3 (44)
	range	3 - 250	100 - 2250	0.7 - 1.8	0.5 - 1.8
nonfiltrable residue ($mg \cdot L^{-1}$)	mean	61	421	22	10
	SD	46 (78)	257 (60)	34(48)	7 (44)
	range	<20 - 208	80 - 1210	<20 - 40	<5 - 34
total residue ($mg \cdot L^{-1}$)	mean	161	637	152	-
	SD	54 (78)	354 (60)	47 (48)	-
	range	79 - 294	189 - 1900	122 - 319	-
total fixed residue ($mg \cdot L^{-1}$)	mean	146	585	119	-
	SD	52 (78)	342 (60)	37 (48)	-
	range	77 - 270	171 - 1800	92 - 246	-
total volatile residue ($mg \cdot L^{-1}$)	mean	18.0	47	35	-
	SD	8.0 (78)	20 (60)	13 (48)	-
	range	<10 - 40	18 - 110	19 - 73	-

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[1] Temperatures recorded by Birtwell *et al*. (1983) for the same August period were 6.0-9.5 in Highet Creek and 13.0-14.5 in Minto Creek.

[2] Number in brackets indicates number of samples analysed.

TABLE 21. Hardness, alkalinity and metal content[a] (mg·L^{-1}) determined for water samples[b] taken from Highet, Minto and Mud creeks during the fish enclosure tests, August and September, 1982.

Variable		Highet Creek		Minto Creek		Mud Creek
		August	September	August	September	September
EDTA hardness[c]		73–75	79–80	110–114	123	141
alkalinity[c]		50–52	51	100–104	112	120
arsenic	(As)	0.1–0.2	<0.05	0.01–0.07	<0.05	<0.05
boron	(B)	<0.001	<0.001	<0.001	<0.001	0.011
barium	(Ba)	0.047–0.049	0.041–0.049	0.066–0.069	0.068	0.094
cadmium	(Cd)	<0.002	<0.002	<0.002	<0.002	<0.002
chromium	(Cr)	<0.005	<0.005	<0.005	<0.005	<0.005
copper	(Cu)	<0.005	<0.005	<0.005	<0.005	<0.005
mercury	(Hg)	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
manganese	(Mn)	0.048–0.052	0.013–0.027	0.014–0.016	<0.001	<0.001
nickel	(Ni)	<0.02	<0.02	<0.02	<0.02	<0.02
lead	(Pb)	<0.02	<0.02	<0.02	<0.02	<0.02
tin	(Sb)	<0.05	0.11–0.17	<0.05	<0.05	<0.05
strontium	(Sr)	0.12–0.13	0.14	0.21	0.23	0.20
zinc	(Zn)	0.05	0.02	0.02–0.03	0.02	0.01
aluminum	(Al)	0.2–0.3	0.1	<0.05–0.06	<0.05	<0.05
iron	(Fe)	0.3–0.5	0.1	0.4–0.5	0.4	<0.01
silicon	(Si)	4.2–4.4	4.3–4.4	2.9–3.0	3.2	2.4
calcium	(Ca)	23.0	25.4–26.0	31.3–32.4	36.1	41.4
magnesium	(Mg)	3.3–3.4	3.5–3.6	7.3–7.5	8.0	9.1
sodium	(Na)	1.6	1.9	1.8	2.1	1.4

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[a] Total metal concentration, based on inductively coupled argon plasma spectrographic analysis.

[b] 4 samples were analysed for each trip and study site except Mud Creek where a single sample was collected.

[c] mg $CaCO_3$·L^{-1}.

TABLE 22. Particle size distribution for suspended sediment sampled from Highet Creek during August and September, 1982.

Particle size[a] (μm)	August 1982 suspensions		September 1982 suspensions	
	weight (%)	cumulative weight (%)	weight (%)	cumulative weight (%)
>400	0	0	0	0
>50	1.5	1.5	0.2	0.2
>25	54.7	56.2	61.0	61.2
>2	29.2	85.4	27.7	88.9
<2	14.6	100.0	11.1	100.0

[a] Measured using the pipet method (Anon. 1975).

TABLE 23. Percentage survival of underyearling Arctic grayling held in Highet Creek or Minto Creek for 4-5 days during August or September, 1982.

Test site	Test period	No. of fish	Source of fish	Length (cm)[a]	Weight (g)[a]	Fish survival (%)				
						24h	48h	72h	96h	120h
Highet Creek	August 5-9	99	Minto Creek	5.3 (0.7)	1.3 (0.6)	100	100	100	100[b]	
Minto Creek	August 5-9	92	Minto Creek	5.2 (0.8)	1.3 (0.5)	100	100	100	100[b]	
Highet Creek	September 10-15	36	Minto Creek	7.4 (1.3)	3.6 (1.9)	100	100	100	100	100
Highet Creek	September 10-15	32	Mud Creek	6.5 (1.1)	2.4 (1.7)	97	97	84	84	84
Minto Creek	September 10-15	35	Minto Creek	8.1 (1.4)	4.5 (2.3)	100	100	100	100	100
Minto Creek	September 10-15	28	Mud Creek	6.5 (0.5)	2.3 (0.7)	100	100	100	100	100

[a] Mean (±SD) values, measured at the termination of the exposure period.

[b] Experiment terminated at 96 h.

TABLE 24. Gill histopathologies[a] for underyearling Arctic grayling held in Minto Creek or Highet Creek during September 1982.

Treatment	Fish no.	Hypertrophy[b]	Hyperplasia[c]	Clubbing[d]	Debris	Parasites[e]
caged in Minto Creek for 4 days	1	+++	++	++	-[f]	++
	2	++	+	+	-	++
	3	++	+++	++	-	+++
	4	+++	++	++	-	++
	5	++	++	+	-	++
caged in Highet Creek for 4 days	6	+++	++	++	+	+++
	7	++	++	++	+	++
	8	++	++	+	++	++
	9	++	++	++	+	++
	10	+++	++	+	+	++
seined from Minto Creek	11	+	+	+	-	+
	12	+	-	+	-	+
	13	-	-	++	-	+

[a] Positive values are based on a scale of 1 to 4, where + = slight; ++ = moderate; +++ = marked; and ++++ = very marked.

[b] Increase in cellular size.

[c] Increase in cellular number.

[d] Thickening of distal ends of lamellae.

[e] Tentatively identified as monogenetic trematodes.

[f] Not evident.

TABLE 25. Mean (±SD) biological characteristics of underyearling Arctic grayling sampled from cages or directly from creeks during August and September, 1982.

No. (n) and source of fish	Date sampled	Treatment	Length (cm)	Weight (g)	Condition factor (K)	Hematocrit (%)	Plasma glucose (mg %)
Mud Creek (19)	09/08/82	seined from creek	5.9±0.6	1.9±0.5	0.88±0.06	43.6±4.9	63.9±8.9
Minto Creek (20)	10/08/82	caged in Minto Creek for 4 days	6.0±0.5	1.7±0.5	0.76±0.08	46.8±4.3	60.7±9.5
Minto Creek (20)	10/08/82	caged in Highet Creek for 4 days	6.1±0.6	1.8±0.5	0.81±0.07	46.1±5.6	81.2±8.8
Minto Creek (30)	14/09/82	seined from creek	7.8±1.0	4.2±1.7	0.86±0.08	44.7±4.3	95.2±19.1
Mud Creek (10)	15/09/82	caged in Minto Creek for 4 days	6.7±0.5	2.4±0.6	0.79±0.07	46.1±4.5	64.1±12.0
Minto Creek (10)	15/09/82	caged in Minto Creek for 4 days	8.9±1.7	5.9±3.0	0.76±0.05	55.6±2.5	132.4±54.9
Mud Creek (10)	15/09/82	caged in Highet Creek for 4 days	7.4±1.5	3.6±2.8	0.77±0.03	50.6±3.7	159.3±69.2
Minto Creek (10)	15/09/82	caged in Highet Creek for 4 days	9.1±0.6	6.3±1.5	0.82±0.05	52.6±4.3	276.4±141.4

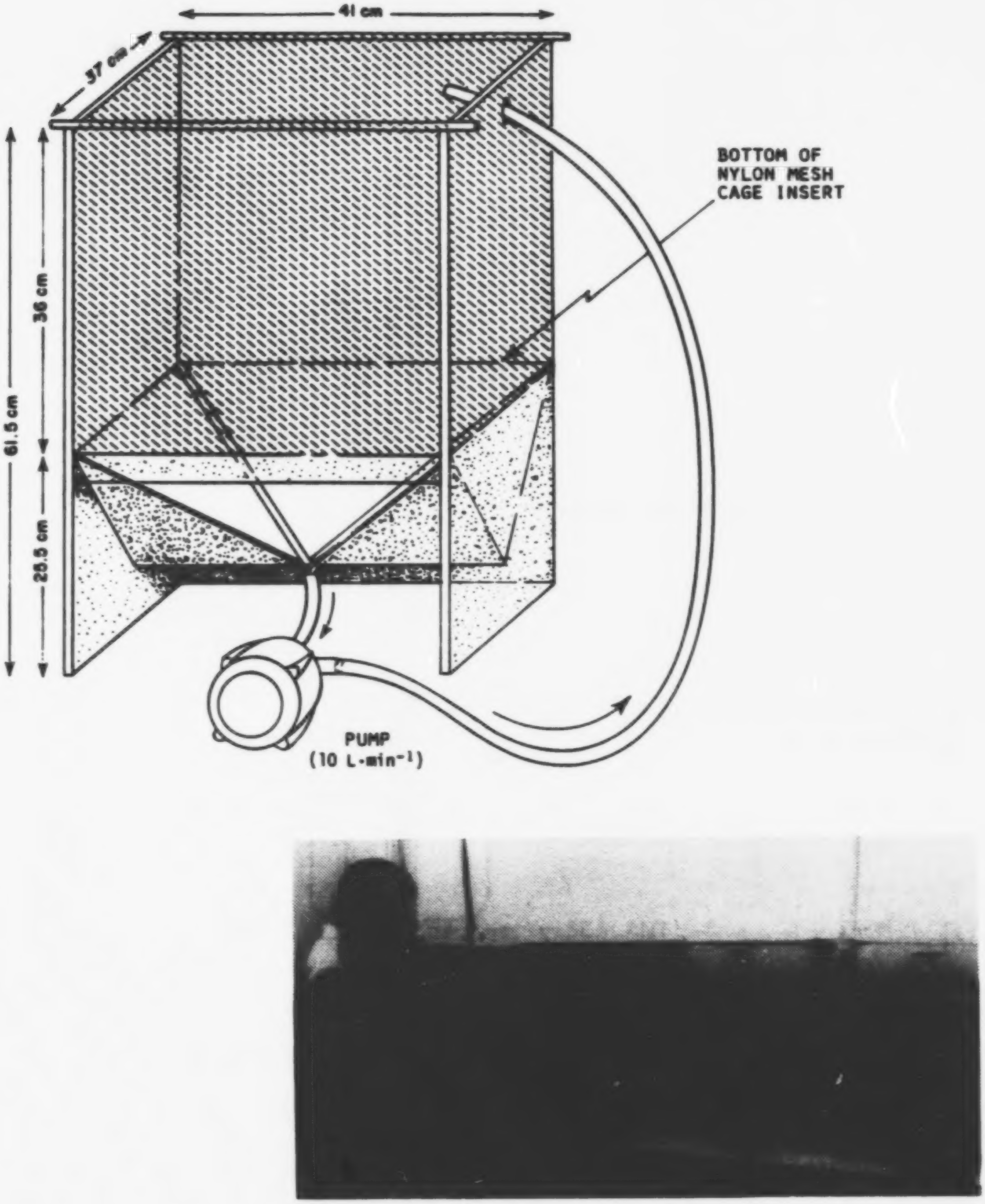
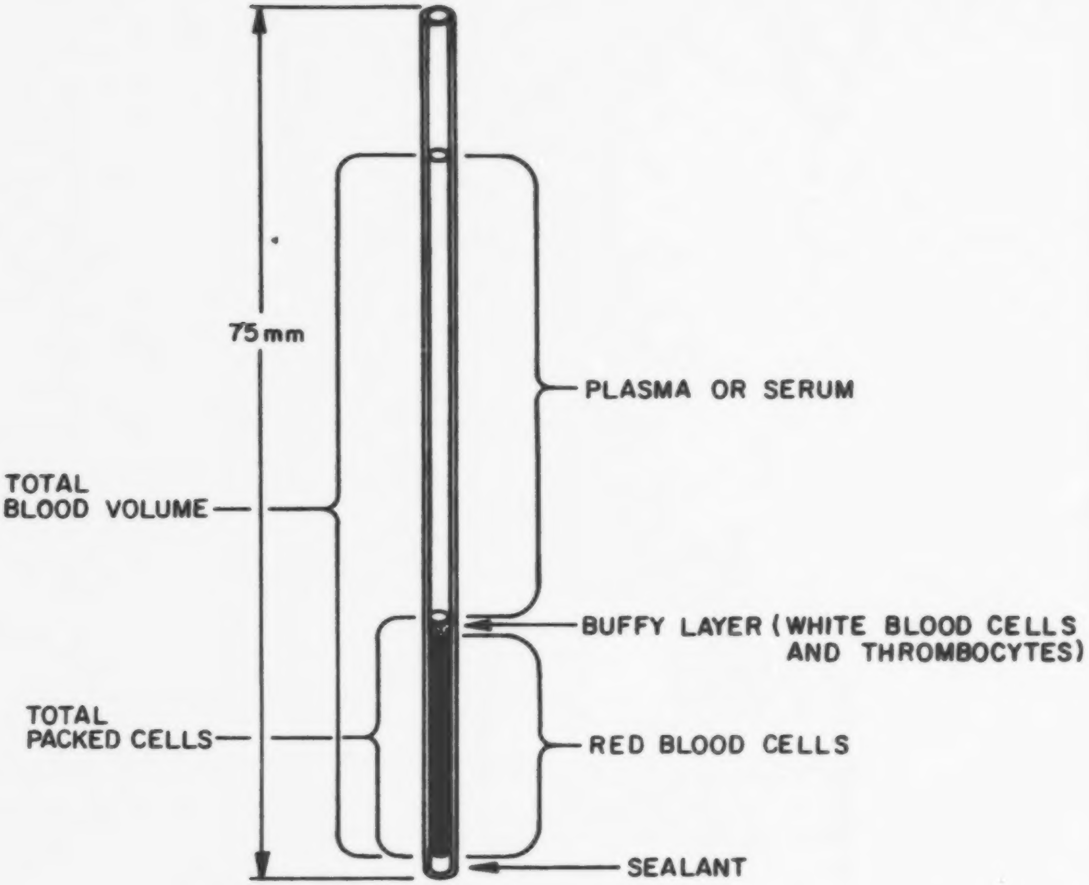

41 cm
37 cm
61.5 cm
36 cm
25.5 cm
BOTTOM OF NYLON MESH CAGE INSERT
PUMP (10 L·min^{-1})

FIG. 1. Illustration of recycle test tanks.


75 mm
PLASMA OR SERUM
TOTAL BLOOD VOLUME
BUFFY LAYER (WHITE BLOOD CELLS AND THROMBOCYTES)
TOTAL PACKED CELLS
RED BLOOD CELLS
SEALANT

$$\text{HEMATOCRIT (\%)} = \frac{\text{HEIGHT OF PACKED CELLS}}{\text{HEIGHT OF TOTAL BLOOD VOLUME}} \times 100$$

$$\text{LEUCOCRIT (\%)} = \frac{\text{HEIGHT OF BUFFY LAYER}}{\text{HEIGHT OF TOTAL BLOOD VOLUME}} \times 100$$

FIG. 2. Illustration of derivation of hematocrit and leucocrit values from a centrifuged blood sample within a heparinized glass capillary tube.

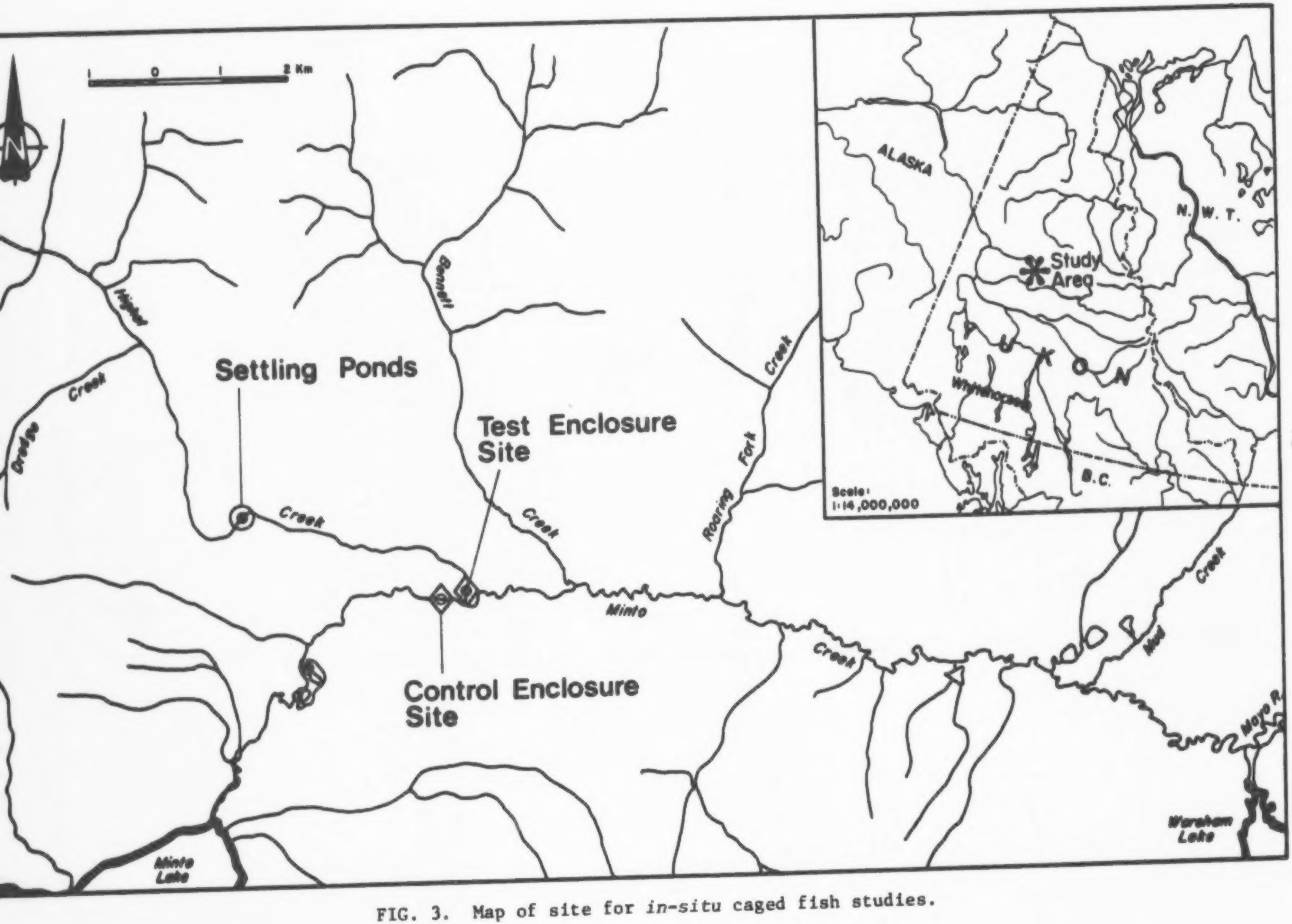

0
1
2 Km
N
Settling Ponds
Test Enclosure Site
Control Enclosure Site
Highet
Creek
Dredge
Creek
Bennett
Creek
Roaring Fork Creek
Minto
Creek
Mud Creek
Mayo R.
Minto Lake
Wareham Lake
ALASKA
Study Area
YUKON
N. W. T.
B.C.
Scale: 1:14,000,000

FIG. 3. Map of site for *in-situ* caged fish studies.

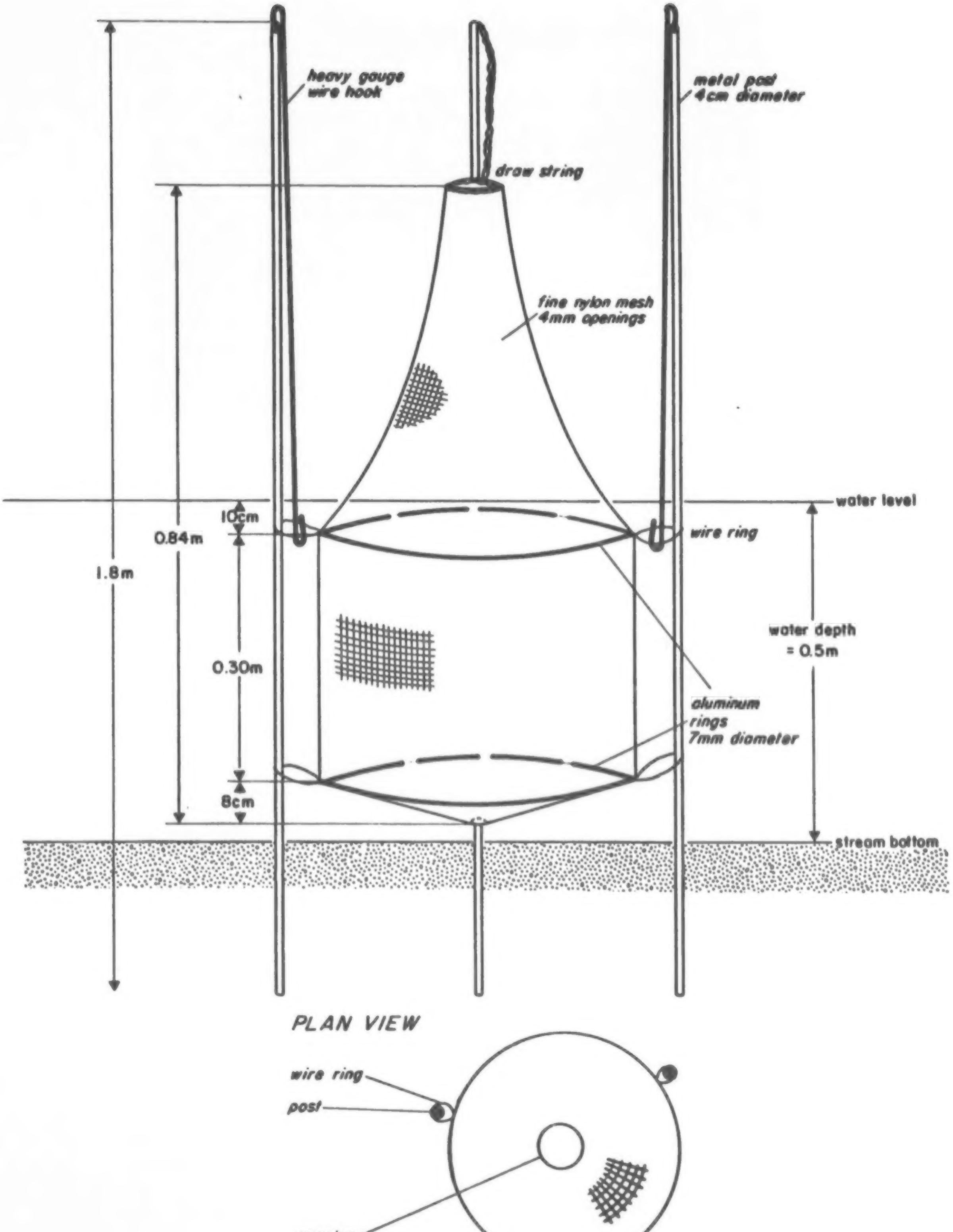

heavy gauge wire hook
metal post 4cm diameter
draw string
fine nylon mesh 4mm openings
water level
10cm
0.84m
1.8m
wire ring
water depth = 0.5m
0.30m
aluminum rings 7mm diameter
8cm
stream bottom
PLAN VIEW
wire ring
post
opening

FIG. 4. Schematic drawing of net enclosures for *in-situ* caged fish studies.

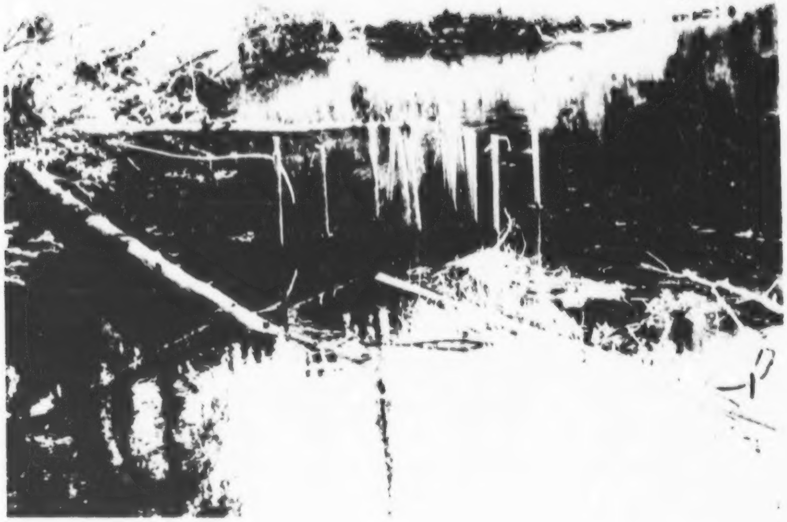


FIG. 5. Study site at Minto Creek. Fish enclosures are shown *in-situ*.

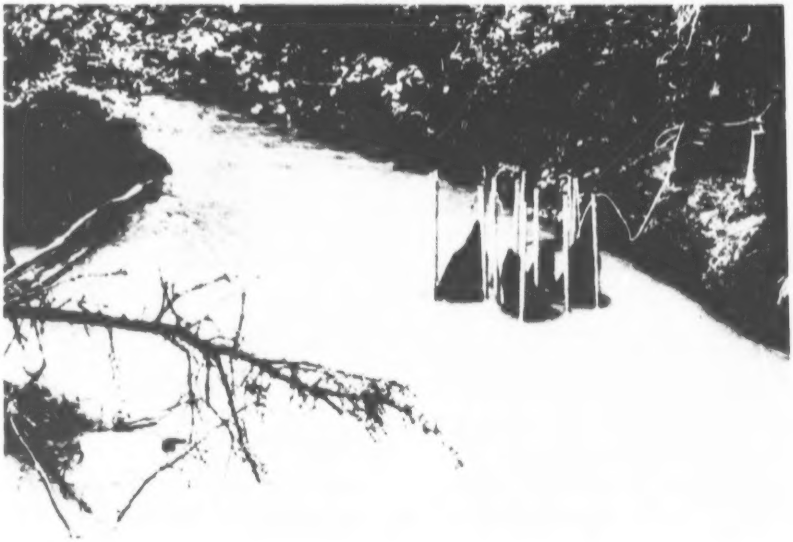


FIG. 6. Study site at Highet Creek. Fish enclosures are shown *in-situ*.

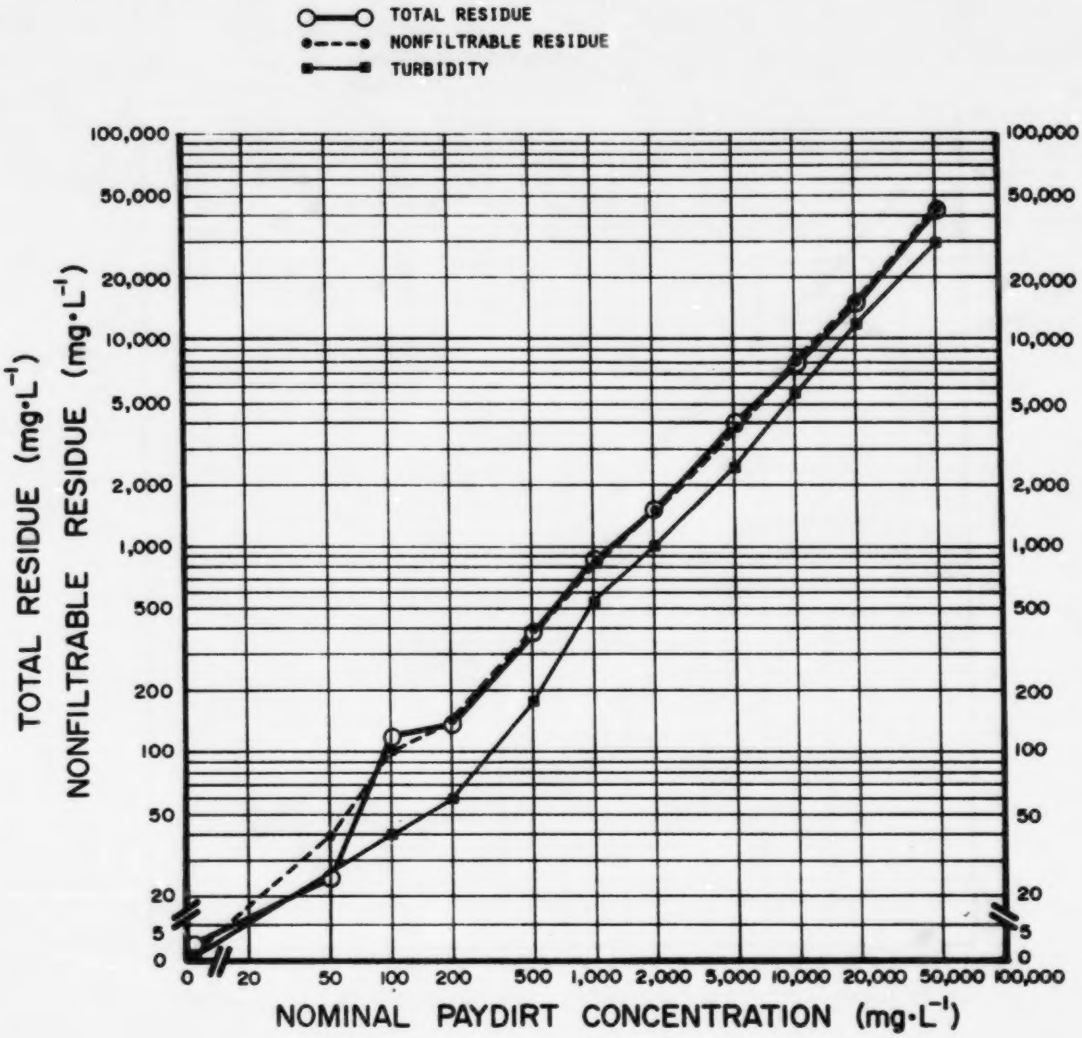


FIG. 7. Relationship of total residue, nonfiltrable residue and turbidity for suspensions of paydirt sediment in freshwater.

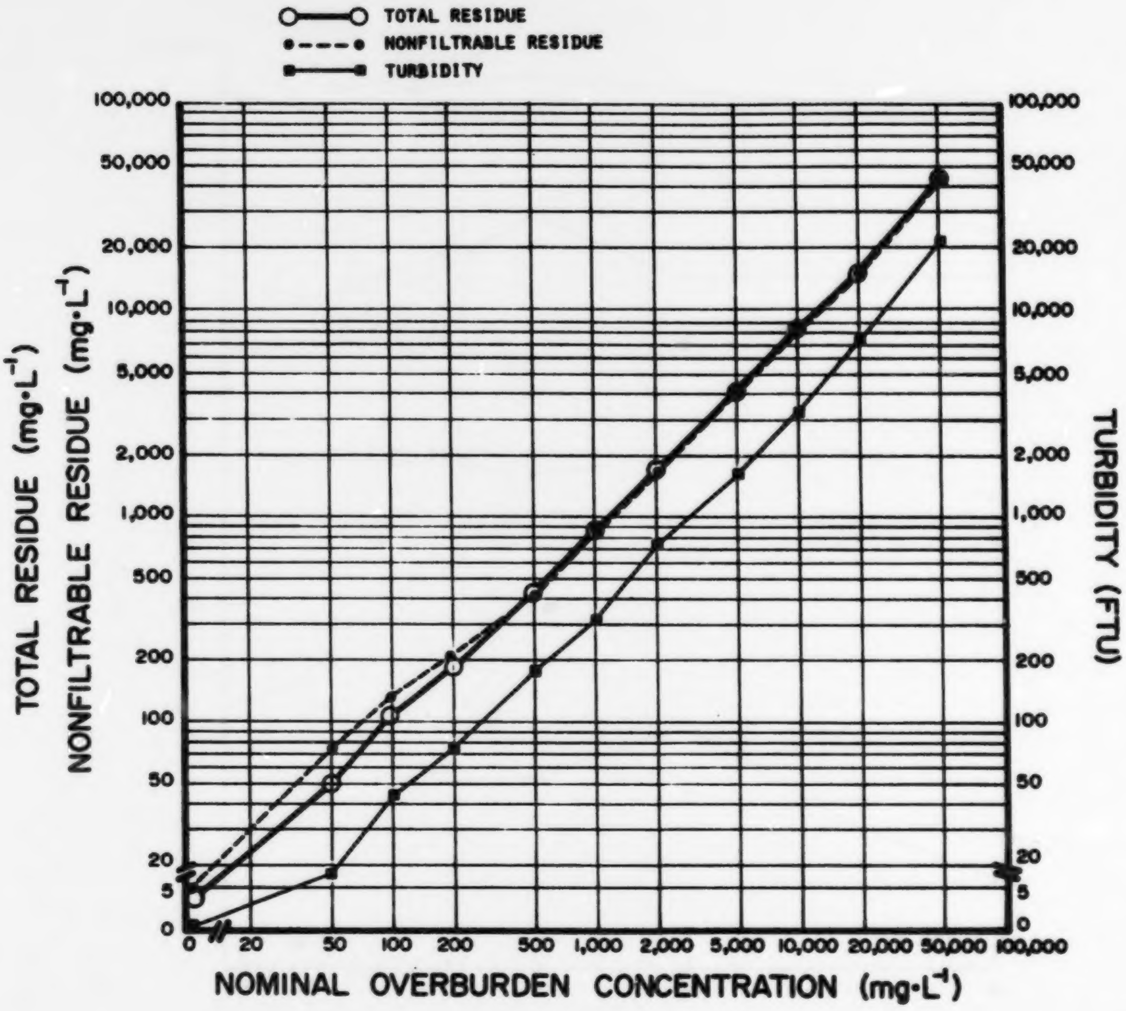


FIG. 8. Relationship of total residue, nonfiltrable residue and turbidity for suspensions of overburden sediment in freshwater.

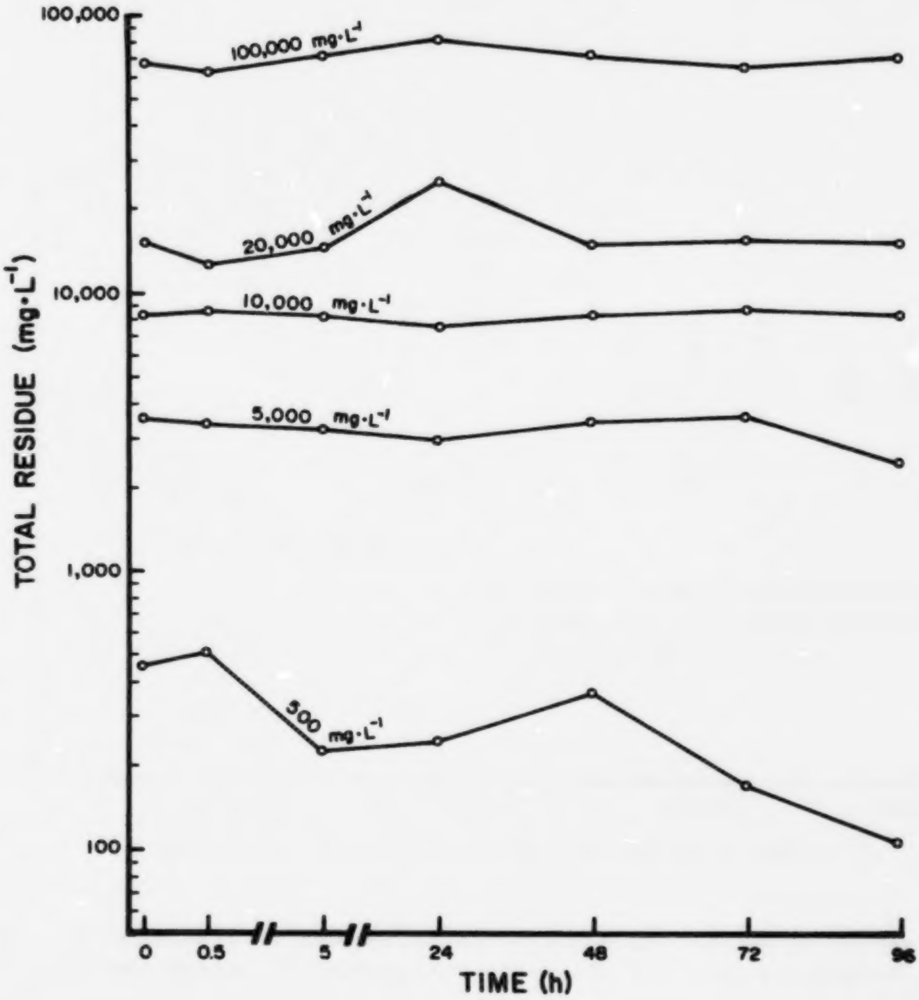
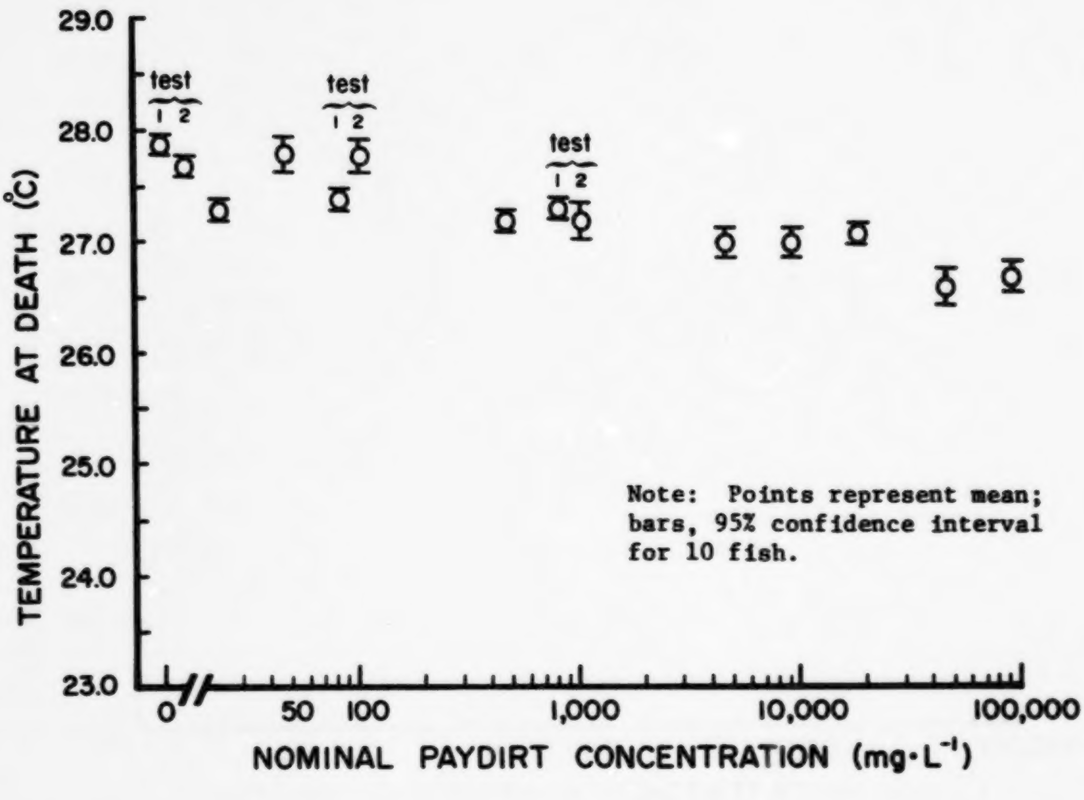


FIG. 9. Illustration of the stability of differing concentrations of suspended paydirt fines within recycle test tanks during a 96-h bioassay.



Note: Points represent mean; bars, 95% confidence interval for 10 fish.

FIG. 10. Relationship of concentration of suspended inorganic paydirt to critical thermal maxima for underyearling Arctic grayling acclimated to 15°C.

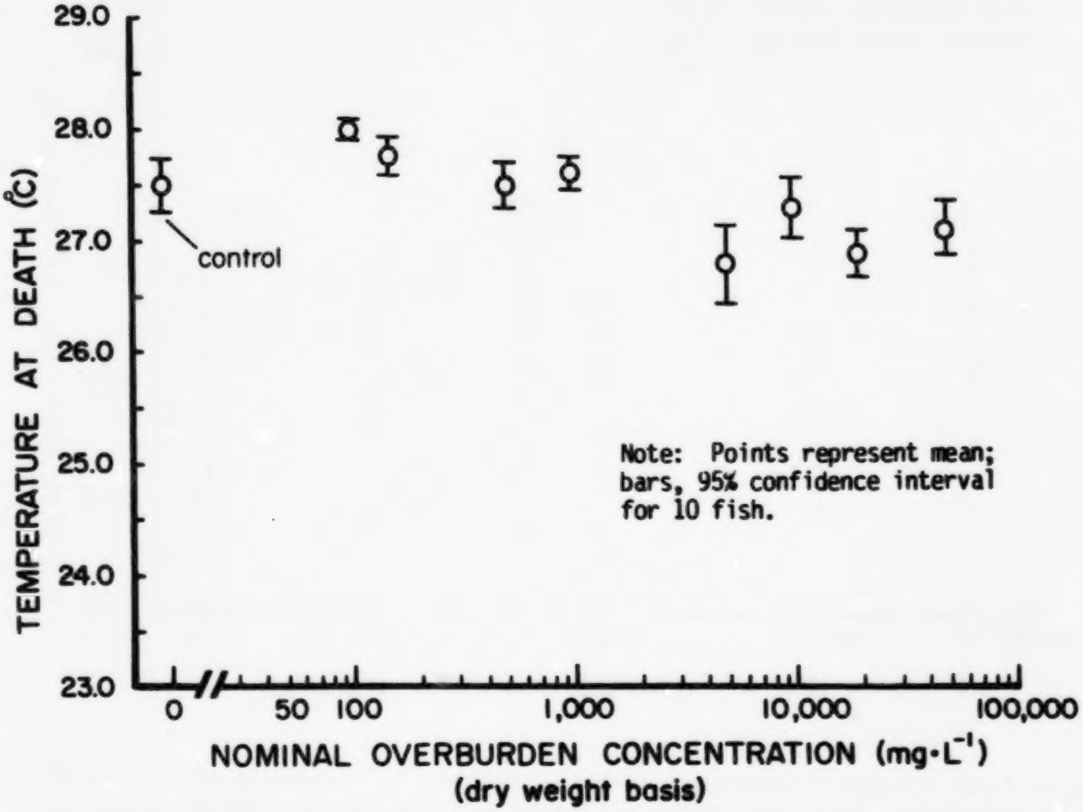


FIG. 11. Relationship of concentration of suspended organic overburden to critical thermal maxima for underyearling Arctic grayling acclimated to 15°C.

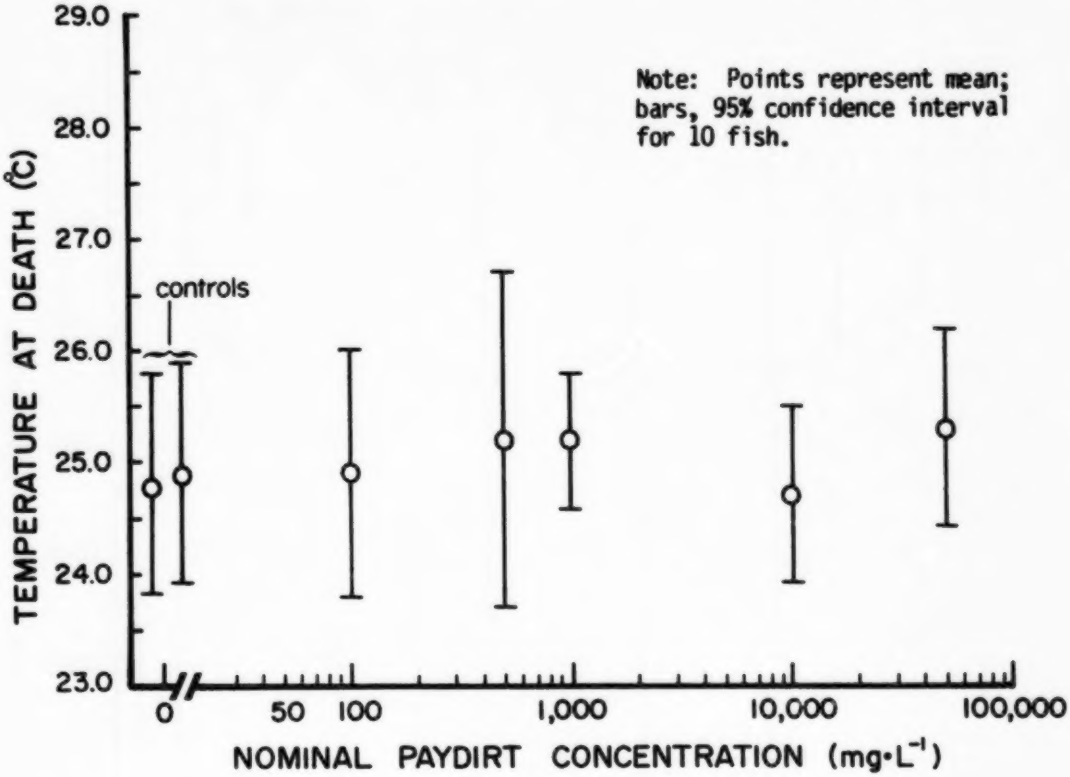


FIG. 12. Relationship of concentration of suspended inorganic paydirt to critical thermal maxima for underyearling Arctic grayling acclimated to 5°C.

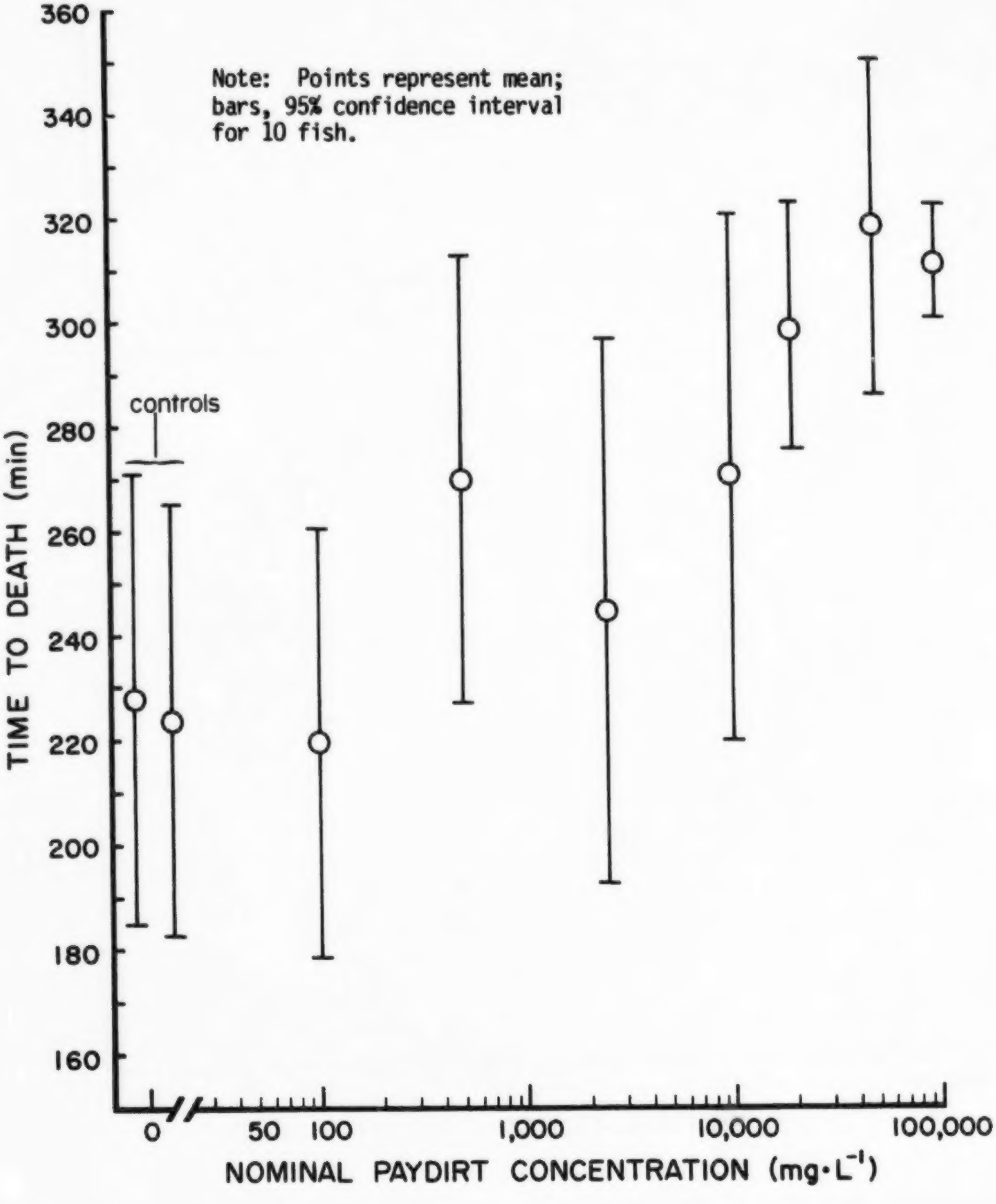


FIG. 13. Relationship of concentration of inorganic paydirt to time to death in sealed jar bioassays for underyearling Arctic grayling acclimated to 15°C and tested at 20°C.

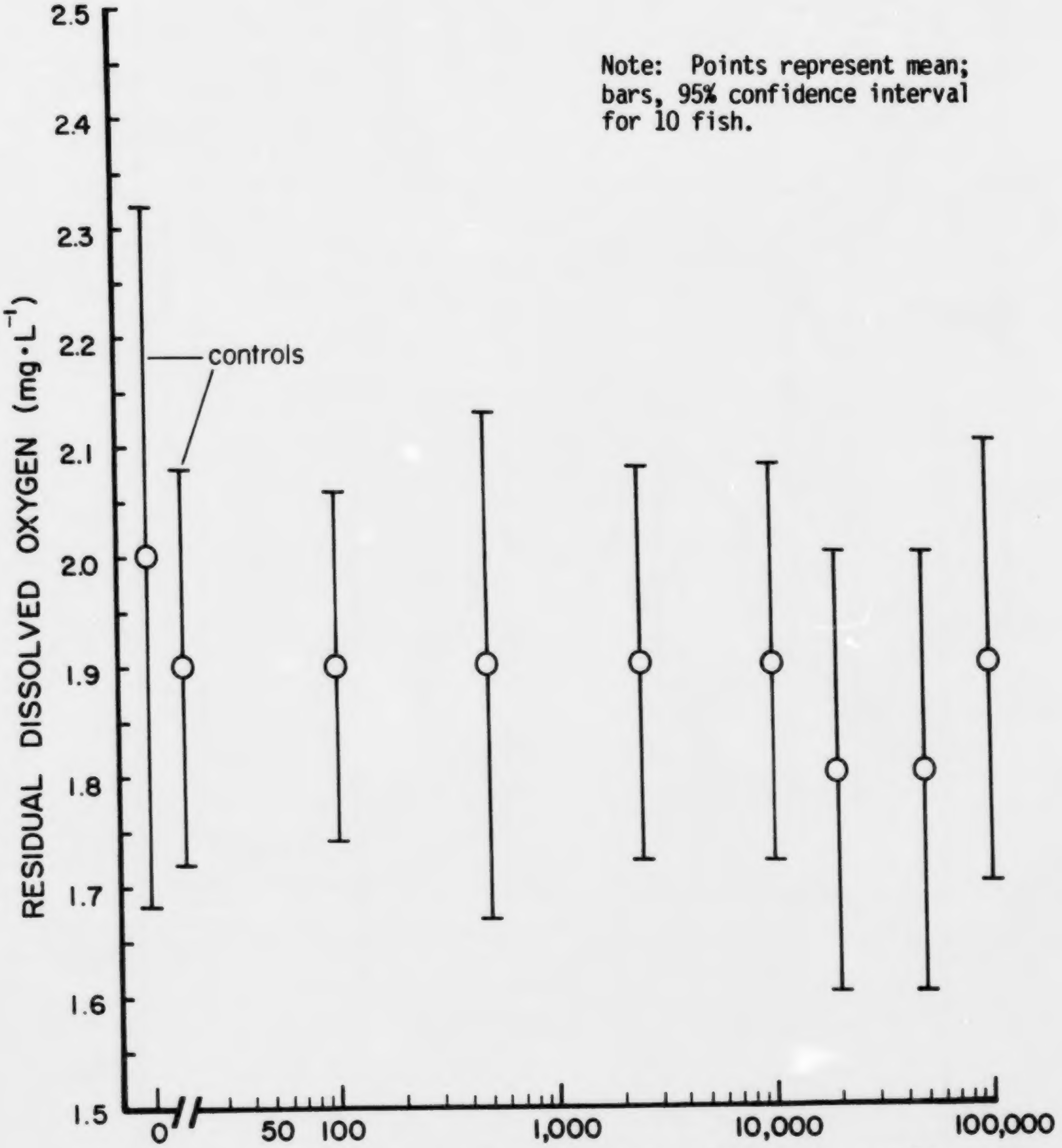


FIG. 14. Relationship of concentration of inorganic paydirt to tolerance to hypoxia in sealed jar bioassays for underyearling Arctic grayling acclimated to 15°C and tested at 20°C.

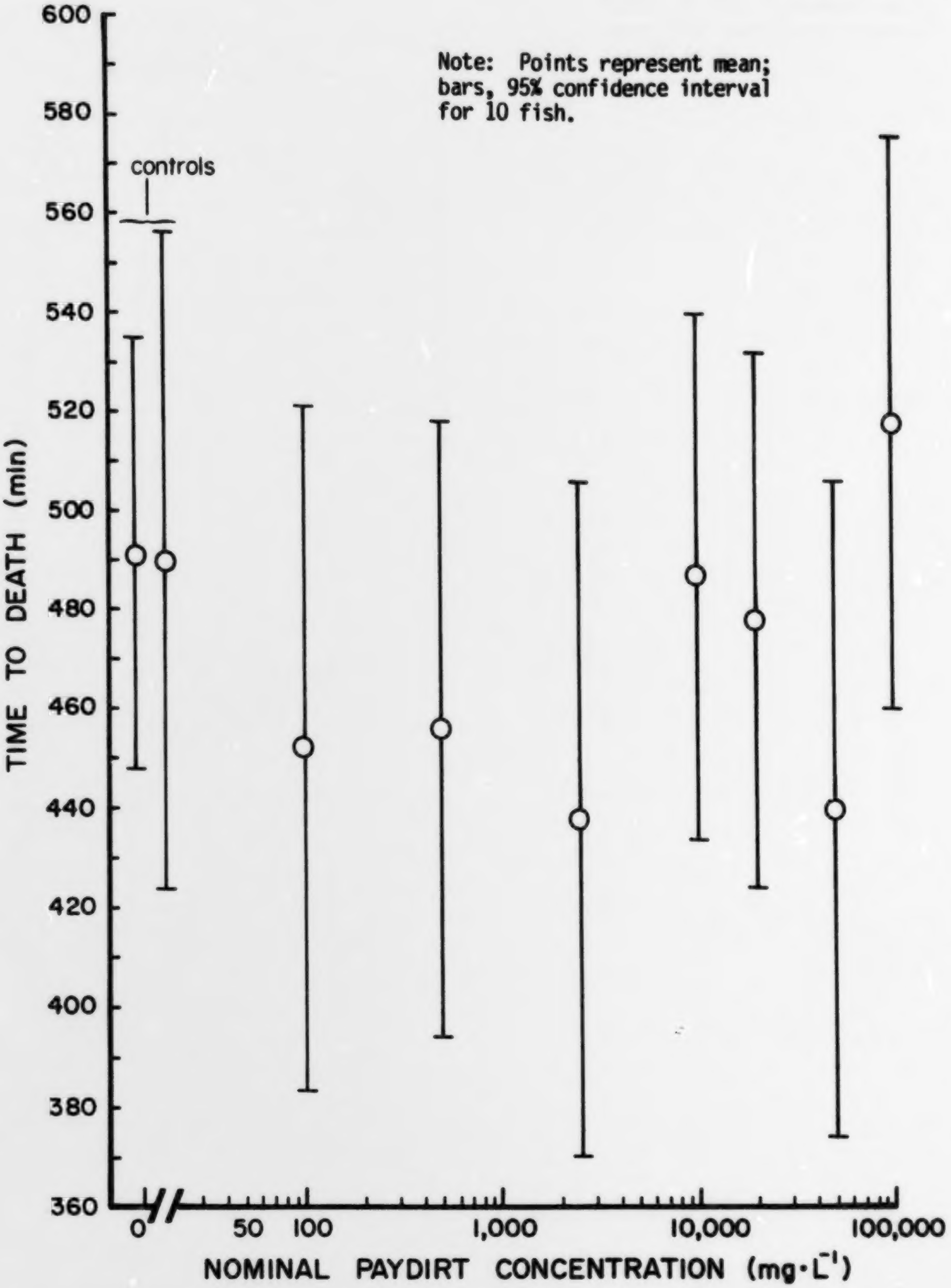


FIG. 15. Relationship of concentration of inorganic paydirt to time to death in sealed jar bioassays for underyearling Arctic grayling acclimated to 5°C and tested at 10°C.

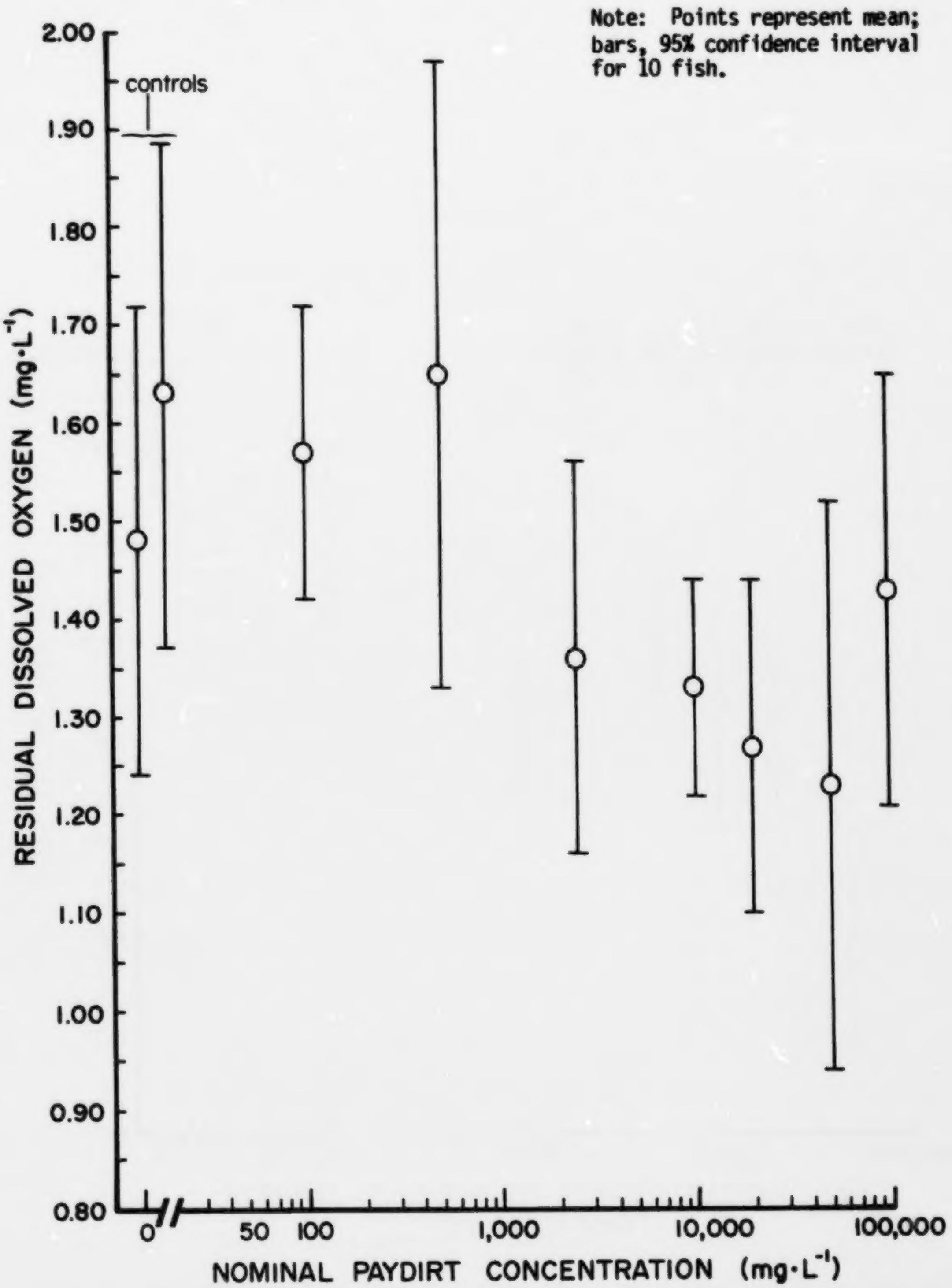


FIG. 16. Relationship of concentration of inorganic paydirt to tolerance to hypoxia in sealed jar bioassays for underyearling Arctic grayling acclimated to 5°C and tested at 10°C.

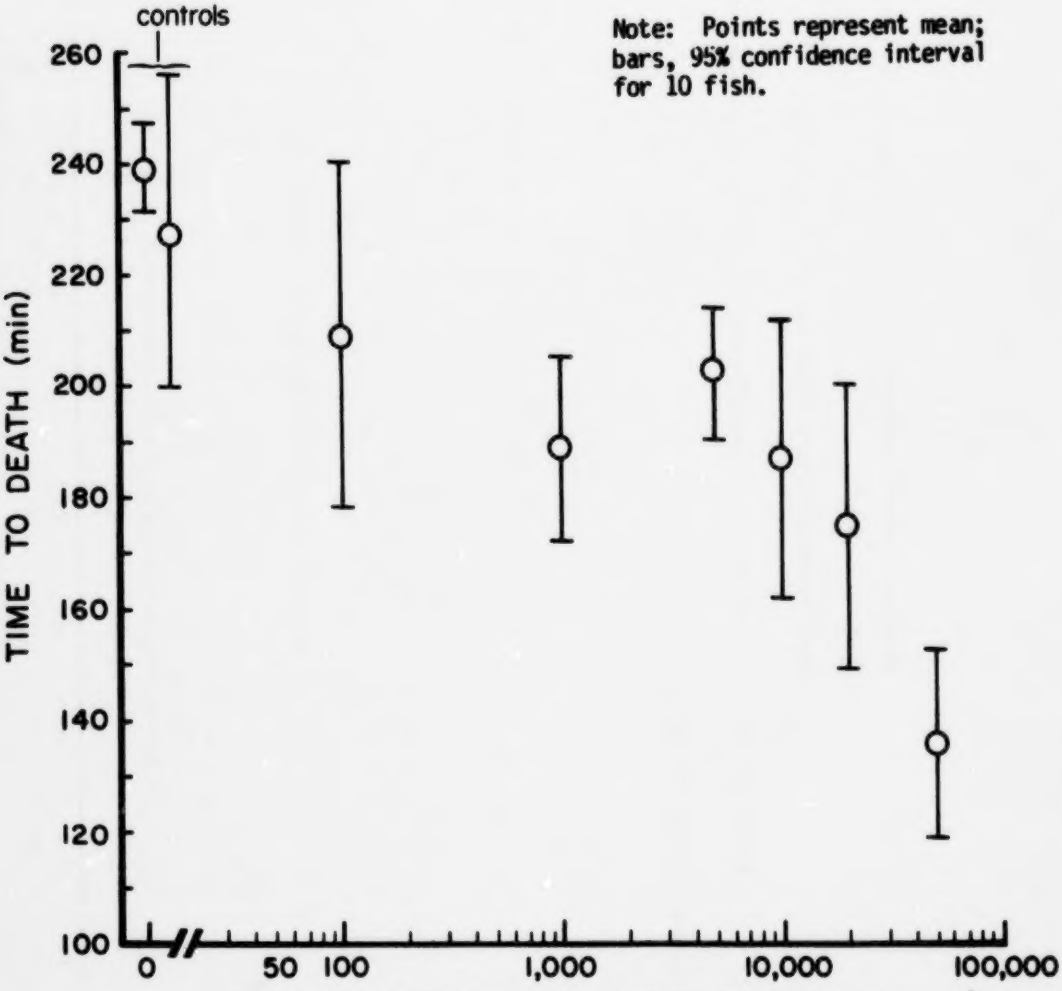


FIG. 17. Relationship of concentration of organic overburden to time to death in sealed jar bioassays for underyearling Arctic grayling acclimated to 15°C and tested at 20°C.

[illegible]

[illegible]

[illegible]

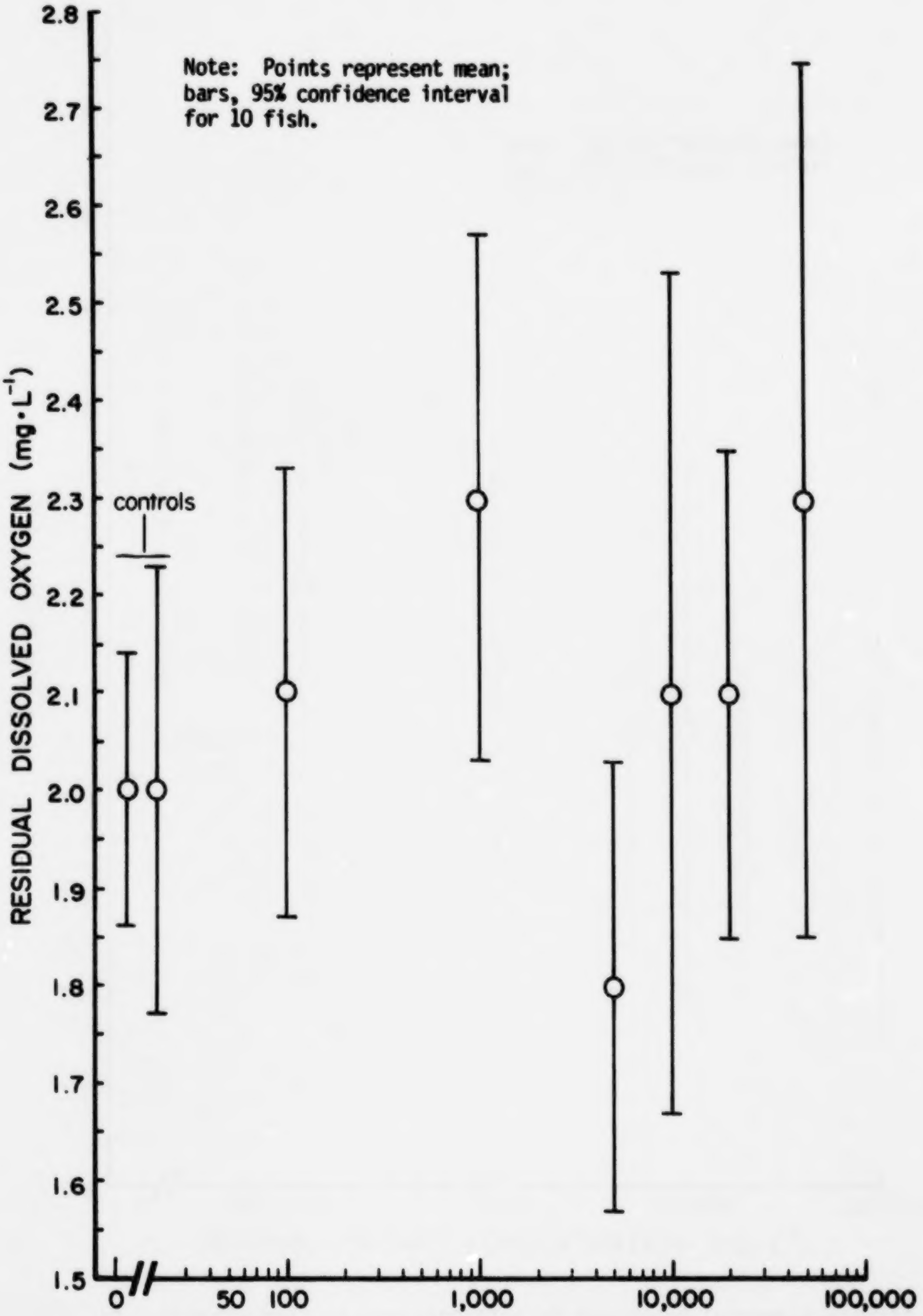


FIG. 18. Relationship of concentration of organic overburden to tolerance to hypoxia in sealed jar bioassays for underyearling Arctic grayling acclimated to 15°C and tested at 20°C.

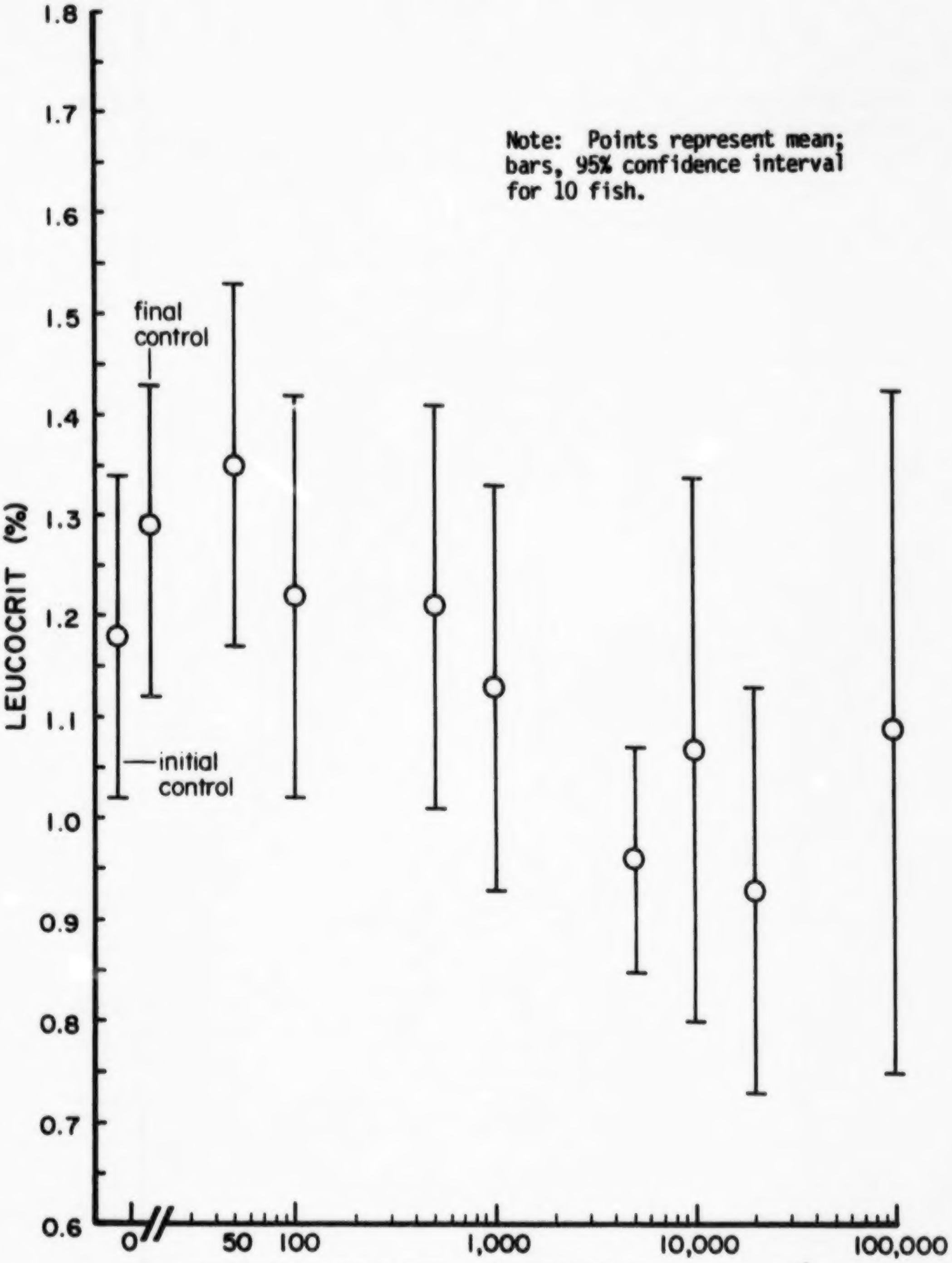


FIG. 19. Relationship of concentration of suspended inorganic paydirt to blood leucocrit values for underyearling Arctic grayling acclimated to 15°C and exposed to sediment for 24 h.

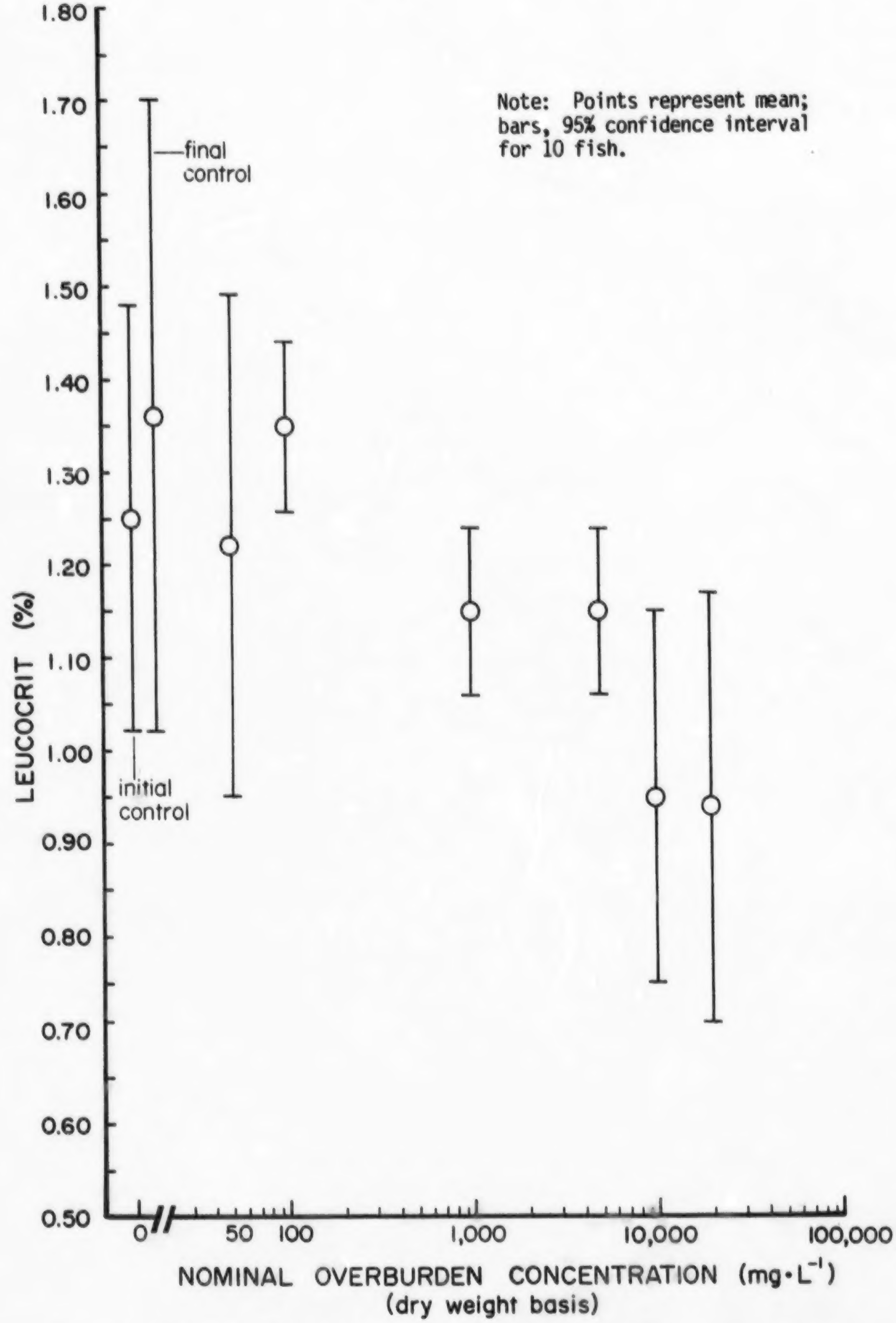


FIG. 20. Relationship of concentration of suspended organic overburden to blood leucocrit values for underyearling Arctic grayling acclimated to 15 °C and exposed to sediment for 24 h.

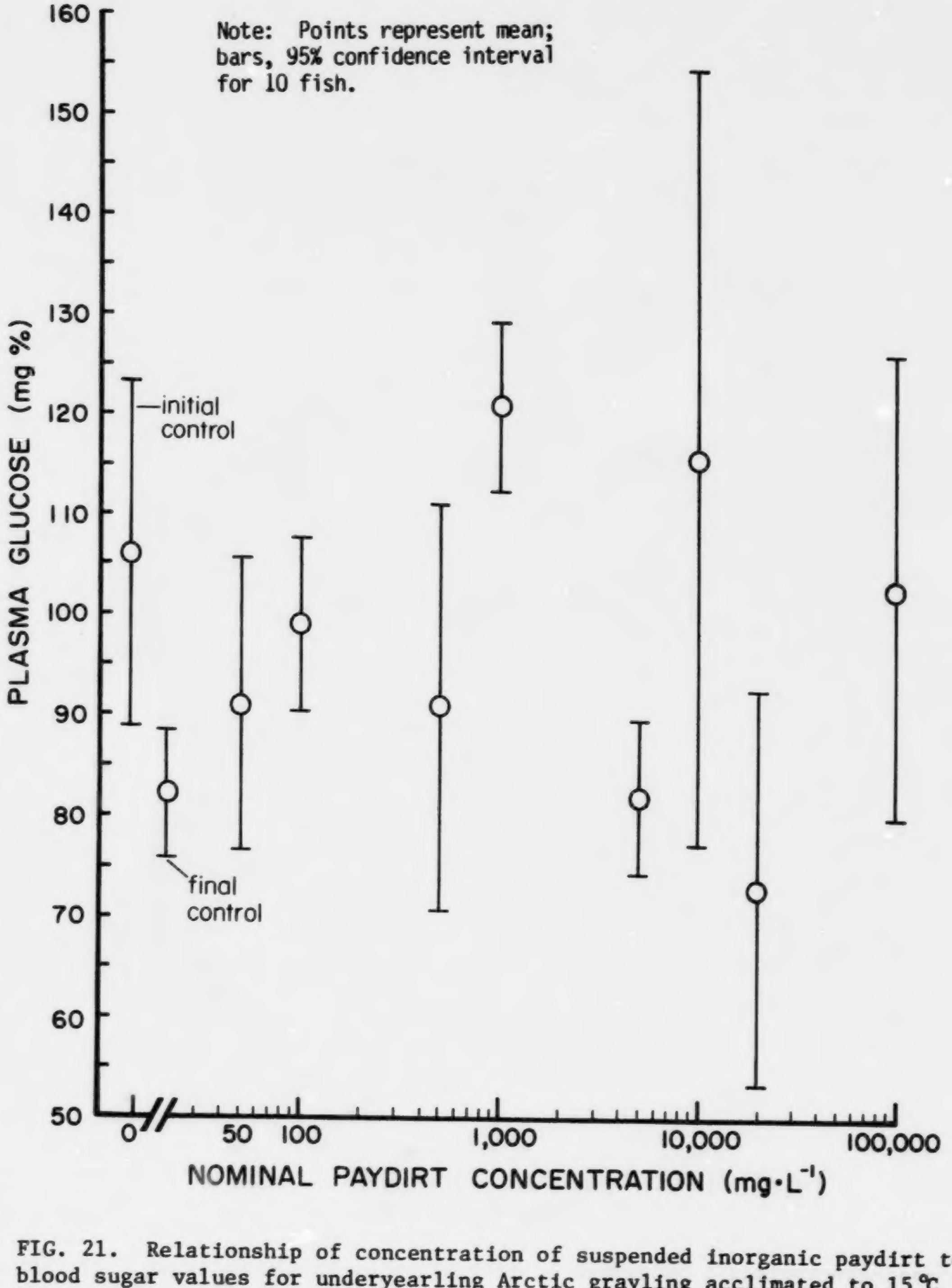


FIG. 21. Relationship of concentration of suspended inorganic paydirt to blood sugar values for underyearling Arctic grayling acclimated to 15 °C and exposed to sediment for 24 h.

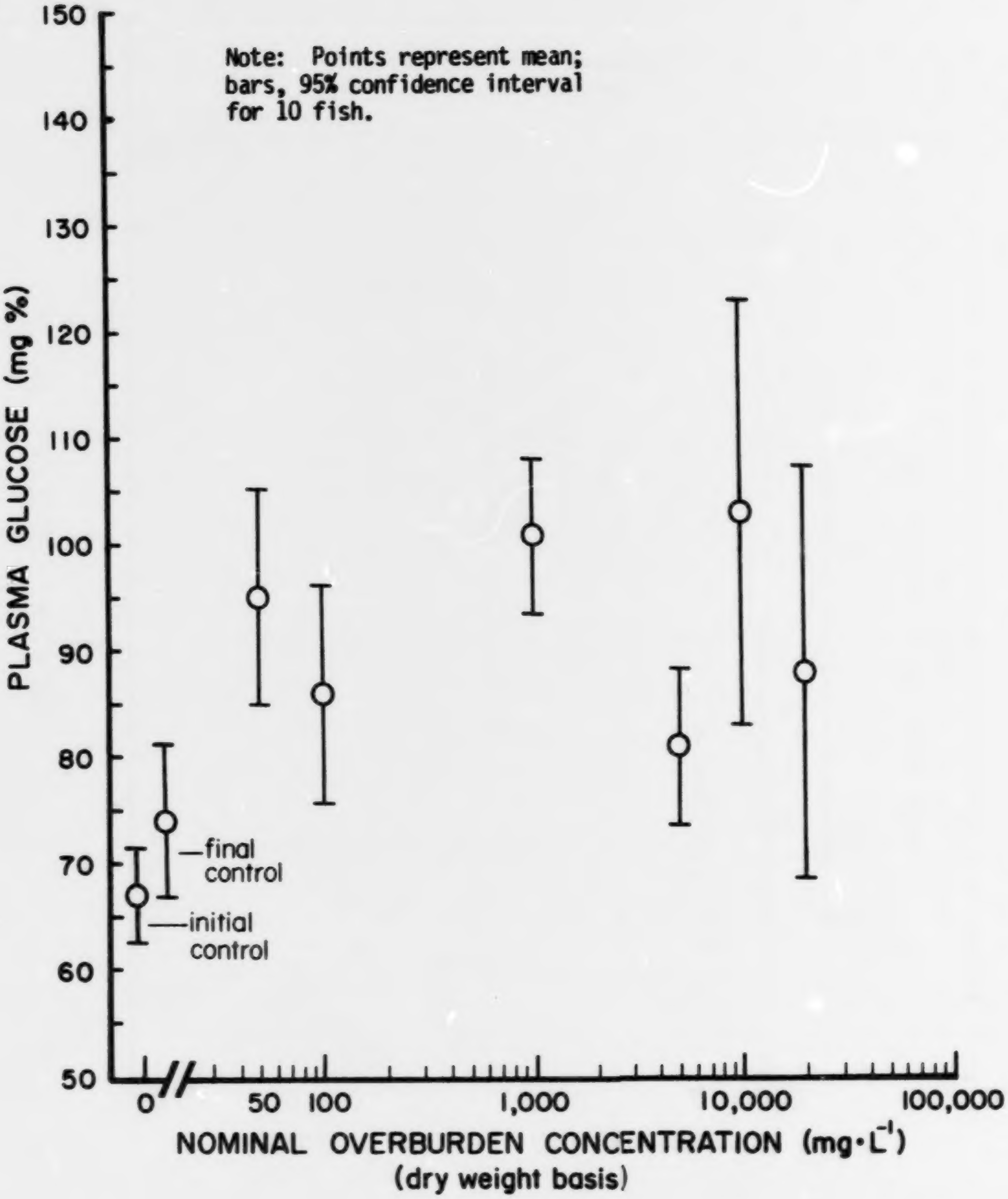


FIG. 22. Relationship of concentration of suspended organic overburden to blood sugar values for underyearling Arctic grayling acclimated to 15°C and exposed to sediment for 24 h.

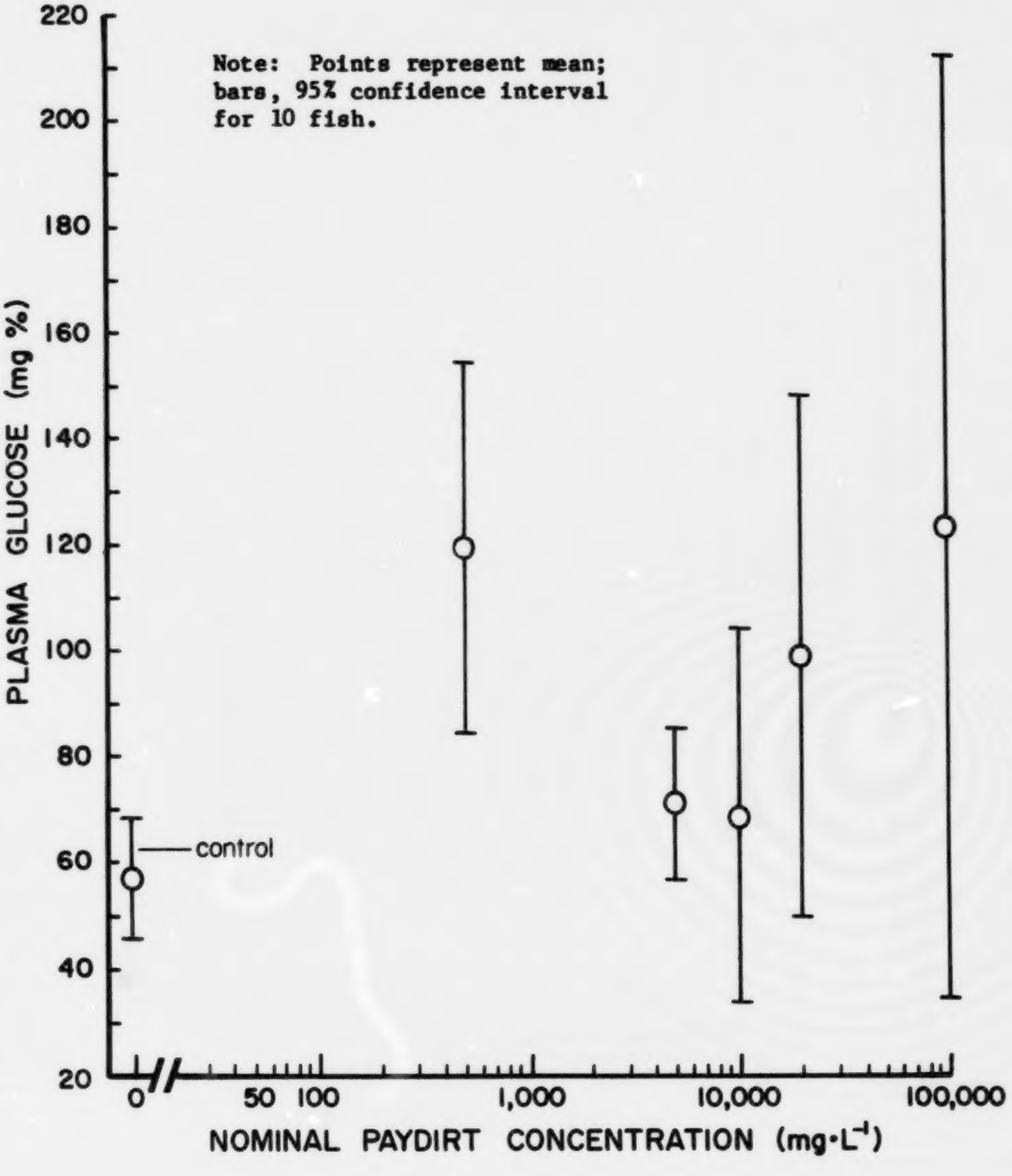


FIG. 23. Relationship of concentration of suspended inorganic paydirt to blood sugar values for underyearling Arctic grayling acclimated to 5°C and exposed to sediment for 96 h.

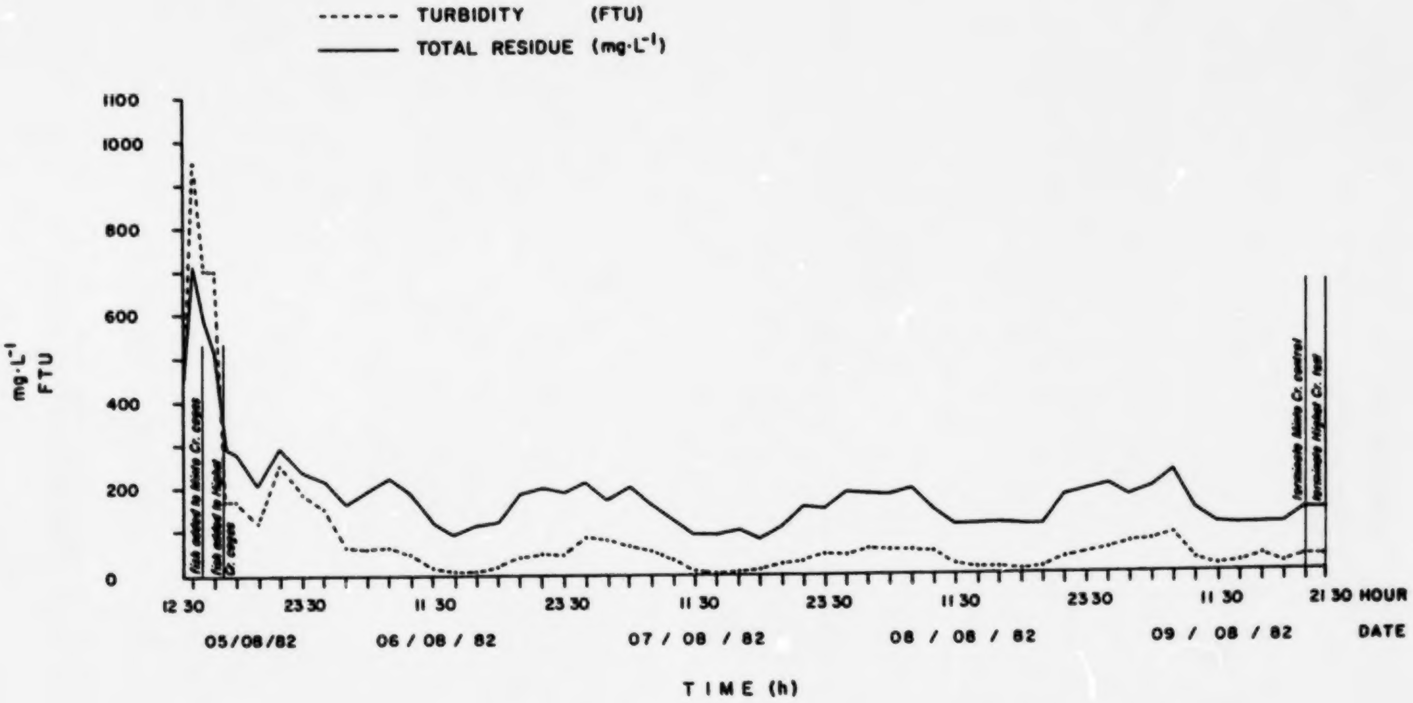


FIG. 24. Illustration of concentration of suspended sediment (total residue) and turbidity within cages held in Highet Creek during August 1982.

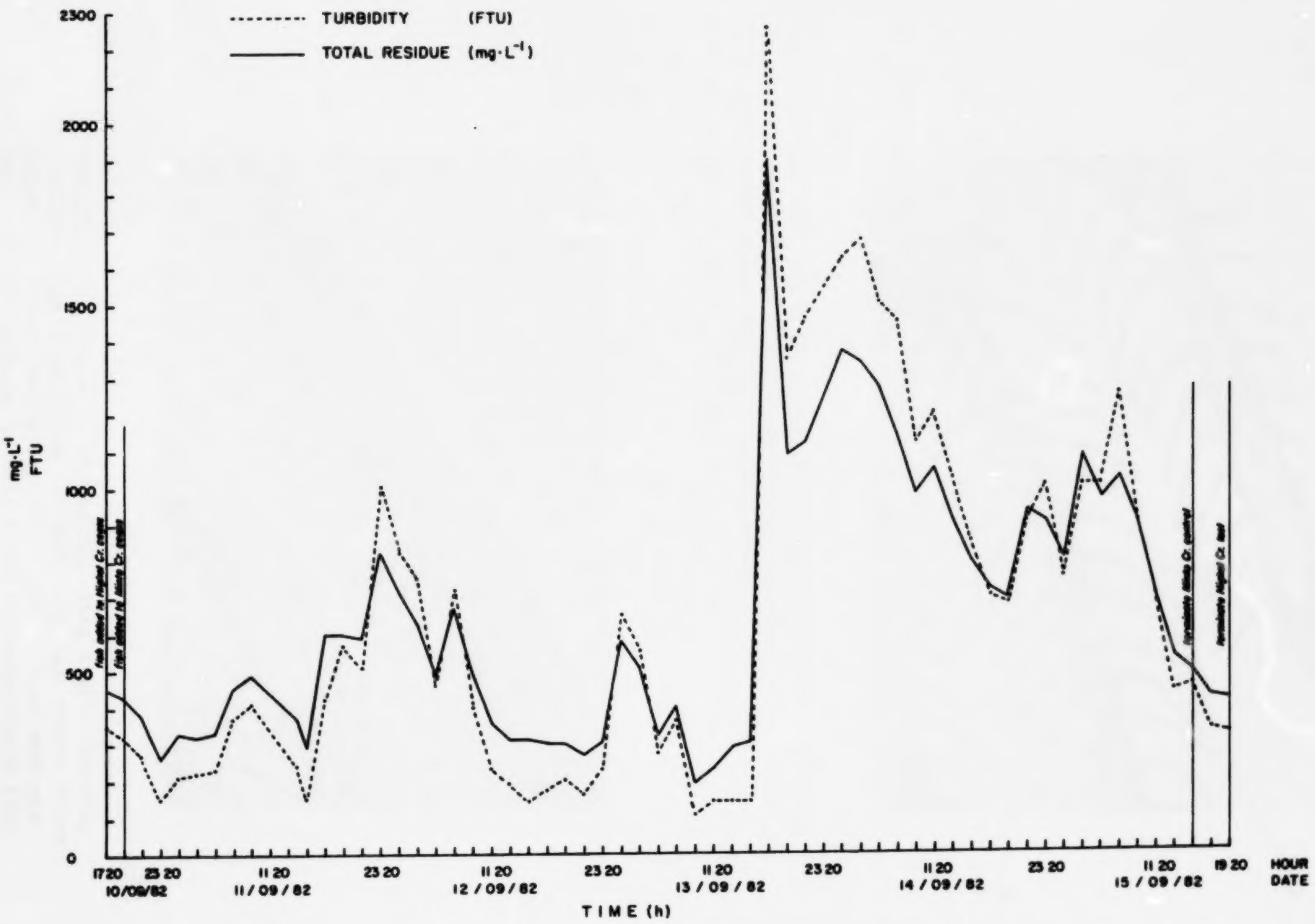


FIG. 25. Illustration of concentration of suspended sediment (total residue) and turbidity within cages held in Highet Creek during September 1982.

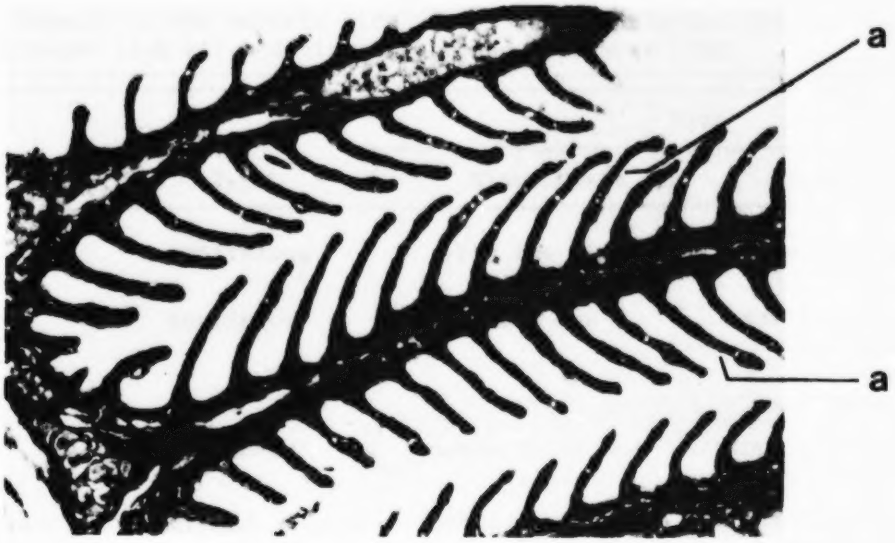


FIG. 26. Gill filaments of underyearling Arctic grayling captured from Minto Creek during September 1982. Note normal appearance of secondary lamellae (a). 300X.

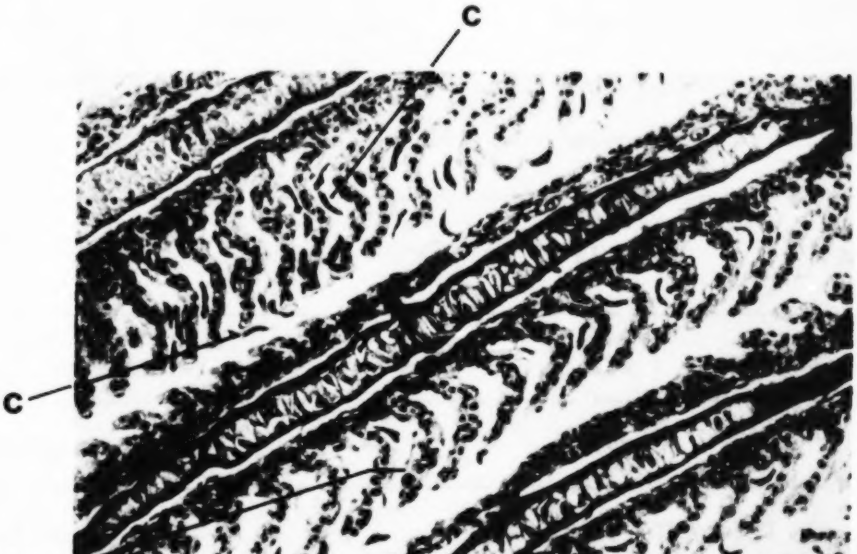


FIG.27. Gill filaments of underyearling Arctic grayling captured from Minto Creek and held in a cage within Minto Creek for 5 days during September 1982. Note moderate hypertrophy (increase in cell size) and hyperplasia (increase in cell numbers) of lamellar epithelium (b), and presence of large numbers of ectoparasites (c). 300X.

APPENDIX 1. Summary of the aquatic biophysical characteristics for the Highet Creek and Minto Creek caged fish sites during August and September 1982.

Variable	Type	Site Minto Creek	Site Highet Creek
riparian vegetation	coniferous	very few *Picea*	several patches of *Picea*
	deciduous	very few	several (*Populus tremuloids*, *P. trichocarpa*, and *Betula*)
	underbrush	dense *Salix* and *Alnus*	continuous cover of *Salix* and *Alnus*
	ground	continuous cover of grasses and berries	few patches of grasses and mosses
channel cover	crown	nil	moderate
	overhang	low/moderate	moderate
biota abundance	aquatic plants	moderate	nil
	stream invertebrates	moderate	low
	algae	moderate	low
predominant flow channel	-	glide	riffle backwater
channel width (m)	-	7.6	3.0
mid-channel depth (m)	-	0.4	0.5
debris abundance	-	moderate	low
bed material	-	60% fines, 40% gravel	100% fines at surface
discharge ($m^3 \cdot s^{-1}$)	August	0.69[a], 0.43[b]	0.32[c]
	September	0.23[d]	0.22[d]

[a] Discharge gauged on August 5, 1982.
[b] Discharge gauged on August 10, 1982.
[c] Discharge gauged on August 7, 1982.
[d] Discharge gauged on September 13, 1982.

APPENDIX 2. Physical/chemical characteristics during 4-day survival test with 15°C-acclimated underyearling Arctic grayling exposed to inorganic paydirt suspensions.

Time (h)	Variable	Nominal paydirt concentration ($mg \cdot L^{-1}$)								
		0	50	100	1,000	5,000	10,000	50,000	100,000	250,000
0	temperature (°C)	15.1	15.2	15.2	15.1	15.1	15.1	15.2	15.2	15.1
	oxygen ($mg \cdot L^{-1}$)	9.3	9.2	9.4	9.3	9.2	9.4	9.3	9.3	9.2
	pH	6.8	7.0	7.0	6.9	7.2	7.2	7.0	7.6	6.8
	conductance[a]	12	12	15	20	20	25	25	25	30
24	temperature	15.8	15.7	15.9	15.6	15.8	16.0	15.8	15.7	15.8
	oxygen	9.0	9.1	9.2	9.1	9.0	9.0	9.2	9.2	9.1
	pH	6.8	7.0	7.0	6.9	7.2	7.2	7.1	7.4	6.9
	conductance	12	15	20	25	30	30	30	30	35
48	temperature	15.9	15.8	15.8	15.7	15.9	15.8	15.6	15.9	15.7
	oxygen	9.2	9.2	9.1	9.0	9.2	9.2	9.1	9.1	9.1
	pH	6.7	7.0	7.0	6.9	7.2	7.2	7.0	7.3	6.8
	conductance	15	20	15	25	30	30	30	30	35
72	temperature	16.0	15.9	15.7	15.9	15.6	15.8	15.8	15.7	15.8
	oxygen	9.1	9.2	9.2	9.1	9.1	9.1	9.0	9.2	9.1
	pH	6.8	6.8	6.7	6.8	6.8	6.7	6.8	6.9	6.8
	conductance	20	25	20	30	30	30	30	30	35
96	temperature	15.8	15.9	15.8	15.9	15.7	15.7	15.8	15.7	15.8
	oxygen	9.1	9.0	9.1	9.2	9.1	9.1	9.0	9.1	9.0
	pH	6.8	6.8	6.7	6.7	6.8	6.8	6.8	6.9	6.8
	conductance	20	20	20	30	30	30	30	30	35

---

[a] $\mu mho \cdot cm^{-1}$.

APPENDIX 3. Physical/chemical characteristics during 4-day survival test with 15°C-acclimated underyearling Arctic grayling exposed to organic overburden suspensions.

Time (h)	Variable	Nominal overburden concentration $(mg \cdot L^{-1})$						
		0	50	100	1,000	5,000	10,000	50,000
0	temperature (°C)	15.1	15.0	15.0	15.0	15.1	15.1	15.0
	oxygen $(mg \cdot L^{-1})$	9.2	9.3	9.2	9.2	9.2	9.3	9.2
	pH	6.9	6.8	6.9	6.8	6.8	6.8	6.9
	conductance[a]	15	15	15	15	20	25	30
24	temperature	15.4	15.1	15.3	15.3	15.3	15.2	15.3
	oxygen	9.1	9.3	9.2	9.2	9.3	9.1	9.3
	pH	6.9	7.0	6.9	6.9	6.9	6.8	6.9
	conductance	18	18	16	20	25	30	35
48	temperature	15.2	15.2	15.1	15.2	15.1	15.1	15.2
	oxygen	9.3	9.3	9.2	9.2	9.2	9.3	9.3
	pH	6.9	7.0	6.9	6.0	7.0	6.9	6.9
	conductance	20	20	20	20	25	35	40
72	temperature	15.1	15.3	15.1	15.2	15.1	15.1	15.2
	oxygen	9.2	9.1	9.2	9.2	9.1	9.2	9.2
	pH	6.8	6.9	6.9	6.9	6.8	6.9	6.9
	conductance	20	20	20	20	25	35	35
96	temperature	15.0	15.1	15.0	15.0	15.1	15.1	15.0
	oxygen	9.3	9.2	9.3	9.3	9.2	9.2	9.2
	pH	6.8	6.8	6.9	6.9	6.8	6.8	6.9
	conductance	20	20	20	25	25	30	35

[a] $\mu mho \cdot cm^{-1}$.

APPENDIX 4. Physical/chemical characteristics during 4-day survival test with 5°C-acclimated underyearling Arctic grayling exposed to inorganic paydirt suspensions.

Time (h)	Variable	Nominal paydirt concentration ($mg \cdot L^{-1}$)					
		0	1,000	5,000	10,000	20,000	100,000
0	temperature (°C)	5.0	5.1	5.0	5.0	5.1	5.0
	oxygen ($mg \cdot L^{-1}$)	10.8	10.8	10.9	10.7	10.8	10.8
	pH	6.8	6.7	6.7	6.7	6.6	6.7
	conductance[a]	18	18	20	30	20	40
24	temperature	5.2	5.2	5.1	5.2	5.0	5.2
	oxygen	10.6	10.6	10.5	10.7	10.7	10.6
	pH	6.7	6.7	6.8	6.7	6.6	6.7
	conductance	18	18	20	30	25	50
48	temperature	4.7	4.4	4.9	4.3	4.6	4.2
	oxygen	10.8	10.8	10.9	10.7	10.8	10.9
	pH	6.8	6.9	6.8	6.8	6.8	6.8
	conductance	15	17	18	23	32	35
72	temperature	5.3	5.0	5.1	5.0	4.9	4.7
	oxygen	10.9	10.7	10.8	10.8	10.8	10.8
	pH	6.7	6.6	6.6	6.7	6.7	6.7
	conductance	15	18	22	25	32	37
96	temperature	5.1	5.0	5.0	5.2	5.3	4.9
	oxygen	10.8	10.8	10.9	10.9	10.6	10.8
	pH	6.7	6.7	6.5	6.5	6.6	6.6
	conductance	18	21	22	29	32	40

[a] $\mu mho \cdot cm^{-1}$.

APPENDIX 5. Residue and turbidity values within a cage held in Highet Creek during the August 1982 *in-situ* fish survival test.

Date	Time (h)	Sample no.	Total residue (mg·L^{-1})	Total fixed residue (mg·L^{-1})	Total volatile residue (mg·L^{-1})	Non-filtrable residue (mg·L^{-1})	Turbidity (FTU)
05/08/82	1330	EX 1	335	279	56	210	180
	1430	EX 2	435	411	24	347	240
	1530	EX 3	416	388	28	314	340
	1630	EX 4	391	369	22	310	380
	1730	EX 5	409	385	24	318	380
	1830	EX 6	381	355	26	298	360
	1930	EX 7	360	339	21	262	320
	2030	EX 8	317	304	13	194	280
	2130	EX 9	309	290	19	214	260
	2230	EX 10	290	277	13	200	225
	2330	EX 11	308	285	23	206	250
06/08/82	0030	EX 12	333	310	23	230	295
	0130	EX 13	335	307	28	242	310
	0230	EX 14	349	307	42	250	325
	0330	EX 15	341	304	37	230	300
	0430	EX 16	341	313	28	206	290
	0530	EX 17	350	319	31	262	310
	0630	EX 18	360	333	27	298	310
	0730	EX 19	382	344	38	246	300
	0830	EX 20	322	291	31	166	280
	0930	EX 21	285	265	20	184	190
	1030	EX 22	222	198	24	134	130
	1130	EX 23	208	197	11	104	115
	1230	EX 24	365	319	46	244	290
	1330	EX 25	466	431	35	392	500
	1430	EX 26	713	668	45	608	950
	1530	EX 27	584	543	41	486	700
	1630	EX 28	510	482	28	424	700
	1730[a]	EX 29	292	259	33	180	165
	1830	EX 30	283	270	13	164	170
	1930	EX 31	-[b]	-	-	-	-
	2030	EX 32	214	201	13	128	120
	2130	EX 33	-	-	-	-	-
	2230	EX 34	294	260	34	208	250
	2330	EX 35	-	-	-	-	-
07/08/82	0030	EX 36	238	220	18	138	185
	0130	EX 37	-	-	-	-	-
	0230	EX 38	215	203	12	126	150
	0330	EX 39	-	-	-	-	-
	0430	EX 40	161	148	13	54	60
	0530	EX 41	-	-	-	-	-

APPENDIX 5 (cont.)

Date	Time (h)	Sample no.	Total residue (mg·L^{-1})	Total fixed residue (mg·L^{-1})	Total volatile residue (mg·L^{-1})	Non-filtrable residue (mg·L^{-1})	Turbidity (FTU)
07/08/82 (cont.)	0630	EX 42	192	171	21	60	55
	0730	EX 43	-	-	-	-	-
	0830	EX 44	218	187	31	108	65
	0930	EX 45	-	-	-	-	-
	1030	EX 46	185	173	12	84	45
	1130	EX 47	-	-	-	-	-
	1230	EX 48	123	112	11	16	17
	1330	EX 49	-	-	-	-	-
	1430	EX 50	96	89	<10	<20	4.8
	1530	EX 51	-	-	-	-	-
	1630	EX 52	109	86	23	<20	4.6
	1730	EX 53	-	-	-	-	-
	1830	EX 54	118	118	<10	<20	15
	1930	EX 55	-	-	-	-	35
	2030	EX 56	186	172	14	70	44
	2130	EX 57	-	-	-	-	-
	2230	EX 58	202	195	<10	92	45
	2330	EX 59	-	-	-	-	-
08/08/82	0030	EX 60	190	195	<10	94	85
	0130	EX 61	-	-	-	-	-
	0230	EX 62	208	202	<10	92	80
	0330	EX 63	-	-	-	-	-
	0430	EX 64	168	174	<10	74	65
	0530	EX 65	-	-	-	-	-
	0630	EX 66	198	183	15	94	54
	0730	EX 67	-	-	-	-	-
	0830	EX 68	157	152	40	38	43
	0930	EX 69	-	-	-	-	36
	1030	EX 70	-	-	-	-	-
	1130	EX 71	-	-	-	-	-
	1230	EX 72	91	88	40	<20	6.8
	1330	EX 73	-	-	-	-	-
	1430	EX 74	92	80	12	<20	3.0
	1530	EX 75	-	-	-	-	-
	1630	EX 76	101	79	22	<20	3.6
	1730	EX 77	-	-	-	-	-
	1830	EX 78	79	79	<10	20	3.8
	1930	EX 79	-	-	-	-	-
	2030	EX 80	105	96	<10	20	20
	2130	EX 81	-	-	-	-	-
	2230	EX 82	154	157	<10	50	26
	2330	EX 83	-	-	-	-	-

APPENDIX 5 (cont.)

Date	Time (h)	Sample no.	Total residue ($mg \cdot L^{-1}$)	Total fixed residue ($mg \cdot L^{-1}$)	Total volatile residue ($mg \cdot L^{-1}$)	Non-filtrable residue ($mg \cdot L^{-1}$)	Turbidity (FTU)
09/08/82	0030	EX 84	149	159	<10	34	38
	0130	EX 85	-	-	-	-	-
	0230	EX 86	184	165	19	38	38
	0330	EX 87	-	-	-	-	-
	0430	EX 88	184	166	18	68	55
	0530	EX 89	-	-	-	-	-
	0630	EX 90	178	157	21	72	55
	0730	EX 91	-	-	-	-	-
	0830	EX 92	197	176	21	82	55
	0930	EX 93	-	-	-	-	-
	1030	EX 94	147	136	11	40	53
	1130	EX 95	-	-	-	-	-
	1230	EX 96	112	105	<10	<20	20
	1330	EX 97	-	-	-	-	-
	1430	EX 98	115	97	18	<20	8.0
	1530	EX 99	-	-	-	-	-
	1630	EX 100	117	92	25	<20	8.0
	1730	EX 101	-	-	-	-	-
	1830	EX 102	112	90	22	20	5.0
	1930	EX 103	-	-	-	-	-
	2030	EX 104	111	87	24	<20	7.5
	2130	EX 105	-	-	-	-	-
	2230	EX 106	169	131	38	58	30
	2330	EX 107	-	-	-	-	-
10/08/82	0030	EX 108	-	-	-	-	-
	0130	EX 109	-	-	-	-	-
	0230	EX 110	199	172	27	88	50
	0330	EX 111	-	-	-	-	-
	0430	EX 112	173	152	21	92	65
	0530	EX 113	-	-	-	-	-
	0630	EX 114	190	168	22	66	68
	0730	EX 115	-	-	-	-	-
	0830	EX 116	230	211	19	58	85
	0930	EX 117	-	-	-	-	-
	1030	EX 118	147	125	22	34	25
	1130	EX 119	-	-	-	-	-
	1230	EX 120	108	77	31	<20	11
	1330	EX 121	-	-	-	-	-
	1430	EX 122	106	89	17	<20	14
	1530	EX 123	-	-	-	-	-
	1630	EX 124	106	97	<10	28	31

APPENDIX 5 (cont.)

Date	Time (h)	Sample no.	Total residue $(mg \cdot L^{-1})$	Total fixed residue $(mg \cdot L^{-1})$	Total volatile residue $(mg \cdot L^{-1})$	Non-filtrable residue $(mg \cdot L^{-1})$	Turbidity (FTU)
10/08/82	1730	EX 125	-	-	-	-	-
(cont.)	1830	EX 126	107	90	17	<20	15
	1930	EX 127	-	-	-	-	-
	2030	EX 128	142	126	16	54	35
	2130	EX 129	-	-	-	-	-
	2230	EX 130	142	130	12	54	30

[a] Fish placed in cages.

[b] Not analysed.

APPENDIX 6. Residue and turbidity values within a cage held in Highet Creek during the September 1982 *in-situ* fish survival test.

Date	Time (h)	Sample no.	Total residue ($mg \cdot L^{-1}$)	Total fixed residue ($mg \cdot L^{-1}$)	Total volatile residue ($mg \cdot L^{-1}$)	Non-filtrable residue ($mg \cdot L^{-1}$)	Turbidity (FTU)
10/09/82	1530	EX 1	504	471	33	396	350
	1630	EX 2	–[b]	–	–	–	–
	1730[a]	EX 3	429	404	25	308	320
	1830	EX 4	–	–	–	–	–
	1930	EX 5	384	360	24	270	270
	2030	EX 6	–	–	–	–	–
	2130	EX 7	260	241	19	144	150
	2230	EX 8	–	–	–	–	–
	2330	EX 9	333	307	26	236	210
11/09/82	0030	EX 10	–	–	–	–	–
	0130	EX 11	321	295	26	214	220
	0230	EX 12	–	–	–	–	–
	0330	EX 13	329	299	30	226	230
	0430	EX 14	–	–	–	–	–
	0530	EX 15	454	419	35	336	370
	0630	EX 16	–	–	–	–	–
	0730	EX 17	492	452	40	326	420
	0830	EX 18	–	–	–	–	–
	0930	EX 19	–	–	–	–	–
	1030	EX 20	–	–	–	–	–
	1130	EX 21	–	–	–	–	–
	1230	EX 22	373	340	33	108	245
	1330	EX 23	292	262	30	222	150
	1430	EX 24	–	–	–	–	–
	1530	EX 25	600	556	44	404	410
	1630	EX 26	–	–	–	–	–
	1730	EX 27	599	550	49	484	570
	1830	EX 28	–	–	–	–	–
	1930	EX 29	592	545	47	470	510
	2030	EX 30	–	–	–	–	–
	2130	EX 31	819	754	65	700	1000
	2230	EX 32	–	–	–	–	–
	2330	EX 33	724	671	53	610	820
12/09/82	0030	EX 34	–	–	–	–	–
	0130	EX 35	629	582	47	490	750
	0230	EX 36	–	–	–	–	–
	0330	EX 37	494	454	40	384	460
	0430	EX 38	–	–	–	–	–
	0530	EX 39	688	635	53	558	720
	0630	EX 40	–	–	–	–	–
	0730	EX 41	492	463	29	358	400
	0830	EX 42	–	–	–	–	–

APPENDIX 6 (cont.)

Date	Time (h)	Sample no.	Total residue (mg·L^{-1})	Total fixed residue (mg·L^{-1})	Total volatile residue (mg·L^{-1})	Non-filtrable residue (mg·L^{-1})	Turbidity (FTU)
12/09/82 (cont.)	0930	EX 43	354	325	29	480	225
	1030	EX 44	-	-	-	-	-
	1130	EX 45	314	292	22	180	190
	1230	EX 46	-	-	-	-	-
	1330	EX 47	309	288	21	202	140
	1430	EX 48	-	-	-	-	-
	1530	EX 49	296	267	29	80	170
	1630	EX 50	-	-	-	-	-
	1730	EX 51	301	270	31	134	200
	1830	EX 52	-	-	-	-	-
	1930	EX 53	271	244	27	156	160
	2030	EX 54	-	-	-	-	-
	2130	EX 55	303	271	32	228	230
	2230	EX 56	-	-	-	-	-
	2330	EX 57	571	527	44	198	650
13/09/82	0030	EX 58	-	-	-	-	-
	0130	EX 59	511	468	43	364	550
	0230	EX 60	-	-	-	-	-
	0330	EX 61	321	288	33	198	270
	0430	EX 62	-	-	-	-	-
	0530	EX 63	346	362	34	278	360
	0630	EX 64	-	-	-	-	-
	0730	EX 65	189	171	18	84	100
	0830	EX 66	-	-	-	-	-
	0930	EX 67	237	218	19	92	145
	1030	EX 68	-	-	-	-	-
	1130	EX 69	284	258	29	130	145
	1230	EX 70	-	-	-	-	-
	1330	EX 71	302	273	29	230	140
	1430	EX 72	-	-	-	-	-
	1530	EX 73	1900	1800	100	485	2250
	1630	EX 74	-	-	-	-	-
	1730	EX 75	1090	1030	60	666	1350
	1830	EX 76	-	-	-	-	-
	1930	EX 77	1120	1040	80	960	1460
	2030	EX 78	-	-	-	-	-
	2130	EX 79	-	-	-	-	-
	2230	EX 80	-	-	-	-	-
	2330	EX 81	1370	1260	110	1276	1625

APPENDIX 6 (cont.)

Date	Time (h)	Sample no.	Total residue ($mg \cdot L^{-1}$)	Total fixed residue ($mg \cdot L^{-1}$)	Total volatile residue ($mg \cdot L^{-1}$)	Non-filtrable residue ($mg \cdot L^{-1}$)	Turbidity (FTU)
14/09/82	0030	EX 82	–	–	–	–	–
	0130	EX 83	1340	1270	70	1210	1675
	0230	EX 84	–	–	–	–	–
	0330	EX 85	1270	1190	80	1100	1500
	0430	EX 86	–	–	–	–	–
	0530	EX 87	1140	1070	70	480	1450
	0630	EX 88	–	–	–	–	–
	0730	EX 89	982	920	62	820	1125
	0830	EX 90	–	–	–	–	–
	0930	EX 91	1050	990	60	292	1200
	1030	EX 92	–	–	–	–	–
	1130	EX 93	913	860	53	468	1025
	1230	EX 94	–	–	–	–	–
	1330	EX 95	786	740	46	596	850
	1430	EX 96	–	–	–	–	–
	1530	EX 97	681	640	41	516	700
	1630	EX 98	–	–	–	–	–
	1730	EX 99	691	650	41	512	680
	1830	EX 100	–	–	–	–	–
	1930	EX 101	928	869	59	740	900
	2030	EX 102	–	–	–	–	–
	2130	EX 103	901	843	58	692	1000
	2230	EX 104	–	–	–	–	–
	2330	EX 105	796	740	56	396	750
15/09/82	0030	EX 106	–	–	–	–	–
	0130	EX 107	1080	1010	70	868	1000
	0230	EX 108	–	–	–	–	–
	0330	EX 109	957	890	67	756	1000
	0430	EX 110	–	–	–	–	–
	0530	EX 111	1020	955	65	800	1250
	0630	EX 112	–	–	–	–	–
	0730	EX 113	904	840	64	700	900
	0830	EX 114	–	–	–	–	–
	0930	EX 115	705	640	65	516	700
	1030	EX 116	–	–	–	–	–
	1130	EX 117	530	470	60	332	440
	1230	EX 118	–	–	–	–	–
	1330	EX 119	492	430	62	308	450
	1430	EX 120	–	–	–	–	–
	1530	EX 121	414	374	78	240	330
	1630	EX 122	–	–	–	–	–
	1730	EX 123	412	360	52	252	320

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[a] Fish placed in cages.

[b] Not analysed.

APPENDIX 7. Residue and turbidity values within a cage held in Minto Creek during the August 1982 *in-situ* fish survival test.

Date	Time (h)	Sample no.	Total residue (mg·L^{-1})	Total fixed residue (mg·L^{-1})	Total volatile residue (mg·L^{-1})	Non-filtrable residue (mg·L^{-1})	Turbidity (FTU)
06/08/82	1420	1	-[b]	-	-	-	-
	1520[a]	2	130	99	31	<20	0.9
	1620	3	-	-	-	-	-
	1720	4	130	92	38	<20	0.9
	1820	5	-	-	-	-	-
	1920	6	134	107	27	<20	0.9
	2020	7	-	-	-	-	-
	2120	8	150	109	41	<20	0.9
	2220	9	-	-	-	-	-
	2320	10	146	127	19	<20	0.9
07/08/82	0020	11	-	-	-	-	-
	0120	12	137	101	36	<20	0.9
	0220	13	-	-	-	-	-
	0320	14	135	106	29	<20	0.9
	0420	15	-	-	-	-	-
	0520	16	133	104	29	<20	0.9
	0620	17	-	-	-	-	-
	0720	18	126	105	21	<20	0.9
	0820	19	-	-	-	-	-
	0920	20	147	112	35	<20	1.1
	1020	21	-	-	-	-	-
	1120	22	152	115	27	<20	1.5
	1220	23	-	-	-	-	-
	1320	24	144	120	24	<20	0.8
	1420	25	-	-	-	-	-
	1520	26	296	230	66	<20	0.8
	1620	27	-	-	-	-	1.1
	1720	28	319	246	73	36	0.8
	1820	29	-	-	-	-	-
	1920	30	193	149	44	24	1.6
	2020	31	-	-	-	-	-
	2120	32	310	242	68	22	1.1
	2220	33	-	-	-	-	-
	2320	34	293	233	60	<20	1.0
08/08/82	0020	35	-	-	-	-	-
	0120	36	135	116	19	20	-
	0220	37	-	-	-	-	-
	0320	38	130	108	22	24	1.0
	0420	39	-	-	-	-	-
	0520	40	129	108	21	20	1.1
	0620	41	-	-	-	-	-
	0720	42	140	106	34	<20	1.3

APPENDIX 7 (cont.)

Date	Time (h)	Sample no.	Total residue (mg·L^{-1})	Total fixed residue (mg·L^{-1})	Total volatile residue (mg·L^{-1})	Non-filtrable residue (mg·L^{-1})	Turbidity (FTU)
08/08/82	0820	43	-	-	-	-	-
(cont.)	0920	44	122	101	21	22	1.3
	1020	45	-	-	-	-	-
	1120	46	130	101	29	20	0.8
	1220	47	-	-	-	-	-
	1320	48	139	115	24	20	1.4
	1420	49	-	-	-	-	-
	1520	50	128	106	22	40	1.6
	1620	51	-	-	-	-	-
	1720	52	126	95	31	<20	1.3
	1820	53	-	-	-	-	-
	1920	54	149	117	32	<20	1.1
	2020	55	-	-	-	-	-
	2120	56	148	115	33	<20	1.1
	2220	57	-	-	-	-	-
	2320	58	145	114	31	<20	1.1
09/08/82	0020	59	-	-	-	-	-
	0120	60	148	116	32	<20	1.1
	0220	61	-	-	-	-	-
	0320	62	141	119	22	<20	0.8
	0420	63	-	-	-	-	-
	0520	64	141	121	20	<20	0.7
	0620	65	-	-	-	-	-
	0720	66	147	113	34	<20	0.8
	0820	67	-	-	-	-	-
	0920	68	152	114	38	<20	1.4
	1020	69	-	-	-	-	-
	1120	70	149	101	48	24	1.1
	1220	71	-	-	-	-	-
	1320	72	146	109	37	24	1.3
	1420	73	-	-	-	-	-
	1520	74	141	106	35	<20	1.3
	1620	75	-	-	-	-	-
	1720	76	-	-	-	-	-
	1820	77	-	-	-	-	-
	1920	78	131	95	36	<20	1.3
	2020	79	-	-	-	-	-
	2120	80	135	96	39	<20	1.1
	2220	81	-	-	-	-	-
	2320	82	-	-	-	-	-

APPENDIX 7 (cont.)

Date	Time (h)	Sample no.	Total residue ($mg \cdot L^{-1}$)	Total fixed residue ($mg \cdot L^{-1}$)	Total volatile residue ($mg \cdot L^{-1}$)	Non-filtrable residue ($mg \cdot L^{-1}$)	Turbidity (FTU)
10/08/82	0020	83	-	-	-	-	-
	0120	84	133	98	35	<20	1.1
	0220	85	-	-	-	-	-
	0320	86	130	96	34	22	1.1
	0420	87	-	-	-	-	-
	0520	88	137	105	32	24	1.1
	0620	89	-	-	-	-	-
	0720	90	154	104	50	24	1.6
	0820	91	-	-	-	-	-
	0920	92	153	110	43	<20	1.6
	1020	93	-	-	-	-	-
	1120	94	147	100	47	<20	1.2
	1220	95	-	-	-	-	-
	1320	96	130	100	30	<20	1.2
	1420	97	-	-	-	-	-
	1520	98	144	114	30	<20	1.2
	1620	99	-	-	-	-	-
	1720	100	141	113	28	<20	1.8

[a] Fish placed in cages.
[b] Not analysed.

APPENDIX 8. Residue and turbidity values within a cage held in Minto Creek during the September 1982 *in-situ* fish survival test.

Date	Time (h)	Sample no.	Non-filtrable residue ($mg \cdot L^{-1}$)	Turbidity (FTU)
10/09/82	1830[a]	1	-[b]	1.8
	1930	2	26	-
	2030	3	<5	1.2
	2130	4	-	-
	2230	5	9	1.1
	2330	6	-	-
11/09/82	0030	7	-	0.7
	0130	8	34	-
	0230	9	-	0.8
	0330	10	-	-
	0430	11	-	1.2
	0530	12	24	-
	0630	13	-	<0.5
	0730	14	-	-
	0830	15	-	-
	0930	16	-	-
	1030	17	-	-
	1130	18	-	-
	1230	19	-	-
	1330	20	-	-
	1430	21	-	-
	1530	22	-	-
	1630	23	-	-
	1730	24	-	-
	1830	25	-	-
	1930	26	-	-
	2030	27	14	1.1
	2130	28	-	-
	2230	29	20	0.6
	2330	30	20	-
12/09/82	0030	31	-	0.7
	0130	32	-	-
	0230	33	20	0.7
	0330	34	-	-
	0430	35	16	0.7
	0530	36	-	0.7
	0630	37	-	-
	0730	38	12	-
	0830	39	-	0.7
	0930	40	14	-
	1030	41	-	0.7
	1130	42	22	-

APPENDIX 8 (cont.)

Date	Time (h)	Sample no.	Non-filtrable residue ($mg \cdot L^{-1}$)	Turbidity (FTU)
12/09/82 (cont.)	1230	43	6	0.8
	1330	44	-	-
	1430	45	14	0.9
	1530	46	-	-
	1630	47	-	0.9
	1730	48	<5	-
	1830	49	-	0.9
	1930	50	5	-
	2030	51	16	1.5
	2130	52	-	-
	2230	53	<5	0.8
	2330	54	12	-
13/09/82	0030	55	-	1.5
	0130	56	-	-
	0230	57	-	0.6
	0330	58	-	-
	0430	59	-	1.2
	0530	60	8	-
	0630	61	-	-
	0730	62	-	0.6
	0830	63	8	0.8
	0930	64	-	<0.5
	1030	65	-	-
	1130	66	<5	-
	1230	67	10	10
	1330	68	-	-
	1430	69	<5	0.9
	1530	70	-	-
	1630	71	<5	1.0
	1730	72	-	-
	1830	73	<5	1.0
	1930	74	<5	-
	2030	75	-	0.7
	2130	76	-	-
	2230	77	<5	0.8
	2330	78	-	-
14/09/82	0030	79	<5	0.8
	0130	80	6	-
	0230	81	-	0.6
	0330	82	-	-
	0430	83	-	-
	0530	84	-	-

APPENDIX 8 (cont.)

Date	Time (h)	Sample no.	Non-filtrable residue ($mg \cdot L^{-1}$)	Turbidity (FTU)
14/09/82 (cont.)	0630	85	–	–
	0730	86	<5	0.7
	0830	87	–	–
	0930	88	–	–
	1030	89	–	–
	1130	90	–	0.9
	1230	91	–	0.9
	1330	92	5	–
	1430	93	<5	1.2
	1530	94	–	–
	1630	95	<5	1.2
	1730	96	–	–
	1830	97	<5	1.1
	1930	98	<5	–
	2030	99	–	1.1
	2130	100	<5	0.8
	2230	101	–	–
	2330	102	8	–
15/09/82	0030	103	–	0.7
	0130	104	–	–
	0230	105	11	1.2
	0330	106	–	–
	0430	107	–	0.5
	0530	108	–	–
	0630	109	6	0.5
	0730	110	–	–
	0830	111	12	0.9
	0930	112	<5	–
	1030	113	–	<0.5
	1130	114	–	–
	1230	115	<5	<0.5

[a] Fish placed in cages.
[b] Not analysed.

APPENDIX 9. Comparison of suspended sediment and turbidity values for triplicate water samples taken from within or outside of a Highet Creek cage during the August and September 1982 *in-situ* fish survival tests.

Date	Sample no.	Nonfiltrable residue ($mg \cdot L^{-1}$)	Total residue ($mg \cdot L^{-1}$)	Turbidity (FTU)
06/08/82	EX 28[a]	424	482	700
	28-2[b]	364	436	580
	28-3[b]	340	456	600
06/08/82	EX 30[a]	164	270	170
	30-2[b]	424	519	300
	30-3[b]	354	455	280
07/08/82	EX 46[a]	84	173	45
	46-2[b]	147	316	45
	46-3[b]	147	254	70
07/08/82	EX 55[a]	88	176	35
	55-2[b]	98	187	42
	55-3[b]	58	158	39
08/08/82	EX 69[a]	34	122	36
	69-2[b]	244	272	50
	69-3[b]	216	375	70
11/09/82	EX 22[a]	108	340	245
	22-2[b]	264	380	250
	22-3[b]	314	438	225
13/09/82	EX 79[a]	304	1160	1550
	79-2[b]	586	1280	1550
	79-3[b]	514	1160	1550

[a] Sample collected by Isco automatic pump sampler from within cage.

[b] Sample collected manually just outside of the cage, at the time that sample "a" was taken.